

**Wildland Fire
Management
Handbook
for Sub-Sahara Africa**



Wildland Fire Management Handbook for Sub-Saharan Africa



**Edited by
Johann G. Goldammer
and Cornelis de Ronde**



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PREFACE

Sub-Sahara Africa – A Fire Subcontinent

Fire is a widespread seasonal phenomenon in Africa. South of the equator, approximately 168 million hectares burn annually, nearly 17% of a total land base of 1014 million hectares, accounting for 37% of the dry matter burned globally. Savanna burning accounts for 50% of this total, with the remainder caused by the burning of fuelwood, agricultural residues, and slash from land clearing. Fires are started both by lightning and humans, but the relative share of fires caused by human intervention is rapidly increasing. Pastoralists use fire to stimulate grass growth for livestock, while subsistence agriculturalists use fire to remove unwanted biomass when clearing agricultural lands, and to eliminate unused agricultural residues after harvest. In addition, fires fuel by wood, charcoal or agricultural residues are the main source of domestic energy for cooking and heating.

In most African ecosystems fire is a natural and beneficial disturbance of vegetation structure and composition, and in nutrient recycling and distribution. Nevertheless, substantial unwarranted and uncontrolled burning does occur across Africa, and effective actions to limit this are necessary to protect life, property, and fire-sensitive natural resources, and to reduce the current burden of emissions on the atmosphere with subsequent adverse effects on the global climate system and human health. Major problems arise at the interface between fire savannas, residential areas, agricultural systems, and those forests which are not adapted to fire. Although estimates of the total economic damage of African fires are not available, ecologically and eco-

nomically important resources are increasingly being destroyed by fires crossing borders from a fire-adapted to a fire-sensitive environment. Fire is also contributing to widespread deforestation in many southern African countries.

Most southern African countries have regulations governing the use and control of fire, although these are seldom enforced because of difficulties in punishing those responsible. Some forestry and wildlife management agencies within the region have the basic infrastructure to detect, prevent and suppress fires, but this capability is rapidly breaking down and becoming obsolete. Traditional controls on burning in customary lands are now largely ineffective. Fire control is also greatly complicated by the fact that fires in Africa occur as hundreds of thousands of widely dispersed small events. With continuing population growth and a lack of economic development and alternative employment opportunities to subsistence agriculture, human pressure on the land is increasing, and widespread land transformation is occurring. Outside densely settled farming areas, the clearance of woodlands for timber, fuelwood and charcoal production is resulting in increased grass production, which in turn encourages intense dry season fires that suppress tree regeneration and increase tree mortality. In short, the trend is toward more fires.

FIRE MANAGEMENT CONSTRAINTS

Budgetary constraints on governments have basically eliminated their capacity to regulate from the centre, so there is a trend towards decentralisation. However, the shortage of resources forcing decentralisation means there is little capacity for governments to support local resource management initiatives. The result is little or no effective management and this problem is compounded by excessive sectoralism in many governments, leading to uncoordinated policy development, conflicting policies, and a duplication of effort and resources. As a result of these failures, community-based natural resource management is increasingly being widely implemented in Africa, with the recognition that local management is the appropriate scale at which to address the widespread fire problems in Africa. The major challenge is to create an enabling rather than a regulatory framework for effective fire management in Africa, but this is not currently in place. Community-based natural resource management programmes, with provisions for fire management through proper infrastructure development, must be encouraged. More effective planning could also be achieved through the use of currently available remotely sensed satellite products.

These needs must also be considered within the context of a myriad of problems facing governments and communities in Africa, including exploding populations and

health crises (e.g. the AIDS epidemic). While unwarranted and uncontrolled burning may greatly affect at the local scale, it may not yet be sufficiently important to warrant the concern of policy makers, and that perception must be challenged as a first step towards more deliberate, controlled and responsible use of fire in Africa.

The prevailing lack of financial, infrastructure and equipment resources for fire management in the Southern African Development Community (SADC) region and neighbouring sub-Saharan Africa goes along with a lack of human resources adequately trained in fire management. The gap between the decreasing fire management resources and the increasing fire problems in the SADC region/sub-Saharan Africa requires immediate response through capacity building.

AFRICA AND THE UN INTERNATIONAL STRATEGY FOR DISASTER REDUCTION (ISDR)

In keeping with the work of the Working Group on “Fire and Related Environmental Hazards” established under the United Nations International Decade for Natural Disaster Reduction (IDNDR), and in accordance with the Framework for the Implementation of the International Strategy for Disaster Reduction (ISDR), the World Conservation Union (IUCN) and its associated partner, the Global Fire Monitoring Center (GFMC) as well as the UN-FAO/ECE/ILO Team of Specialists on Forest Fire, suggested, in 2000, the creation of an inter-agency “Working Group on Wildland Fire”.

This proposal was in line with several declarations made in international conferences during the last five years and is intended to bring together both the technical members of the fire community and the authorities concerned with policy and national practices in wildland fire management to realise their common interests of fire risk management and disaster reduction at global scale. The UN-ISDR Inter-Agency Task Force for Disaster Reduction (IATF) at its second meeting on 11 October 2000 agreed to establish the Working Group on Wildland Fire.

Through the Working Group it is envisaged to establish an inter-agency and inter-sectoral forum of UN and other international agencies and programmes, and mechanisms of information and task sharing in the field of reducing the negative impacts of fire on the environment and humanity.

Three priority fields of activity are being addressed by the Working Group on Wildland Fire:

- Establishment of, and operational procedures for, a global network of regional- to national-level focal points for early warning of wildland fire, fire monitoring and

impact assessment, aimed at enhancing existing global fire monitoring capabilities and facilitating the functioning of a global fire management working programme or network.

- Development of a proposal for internationally agreeable criteria and common procedures / guidelines for fire data collection and fire damage assessment with the overall aim of generating knowledge required by the various user communities at global, regional, national and local levels.
- Strengthening the existing regional, national and local capabilities in fire management and policy development through information dissemination and networking.

Mandated and supported by the members of the Working Group on Wildland Fire, the GFMC began to facilitate the establishment of the Global Wildland Fire Network in 2002–2003. This network intends to encourage countries to establish or expand cooperative and networking activities between countries at regional level. In some regions of the world such regional networking activities already existed under various umbrellas. These networks were encouraged to join the Global Wildland Fire Network.

In order to address the serious fire situation in sub-Saharan Africa where no such networking activity was in place, the Regional Sub-Saharan Fire Management Network (AFRIFIRENET) was founded in July 2002 under the auspices of the GFMC and the Working Group on Wildland Fire. The objectives of the network include:

- Establishment and maintenance of the network through multilaterally agreed mechanisms of communication and information sharing.
- Establishment of partnerships with topical networks, e.g. fire monitoring, early warning of fire, wildland fire science, fire management cooperation and training, etc.
- Regular communication with network members; contribution to and circulation of International Forest Fire News (IFFN).
- Support of the establishment and facilitating access – and the use of – remote sensing and related technologies for fire and fuel monitoring, fire management planning and wildfire impact assessment.
- Creation of an early wildland fire warning system.
- Contribution to a global fuel status, fire monitoring and impact assessment programme which will secure the contribution for and by the continent.
- Improvement of integrated fire management at regional and national scale.

- Improved research and technology with regard to fire science, and to stream-line technology transfer.
- Assisting in wildfire disaster management (emergency support).
- Providing/facilitating training at all levels of fire management.
- Promoting communication between wildland fire disciplines of Africa and from other continents, under the umbrella of the GFMC.
- Contributing to the New Partnership for Africa's Development (NEPAD).

For details see:

<http://www.fire.uni-freiburg.de/GlobalNetworks/Africa/Afrifirenet.html>

AFRIFIRENET has already established cooperative agreements with other topical networks. A main partner of AFRIFIRENET is the Global Observation of Forest Cover/ Global Observation of Landcover Dynamics (GOFC/GOLD) – Fire Mapping and Monitoring Regional Southern Africa Team (SAFNet).

In support of the urgently required fire management training activities in sub-Saharan Africa the GFMC and the coordinator of AFRIFIRENET have prepared this handbook. The first edition of this handbook does not yet provide the full background and experience of fire management of francophone West Africa. However, the editors have been very pleased with a contribution from West Africa which was submitted in the final stage of the production of this volume. This paper has been inserted as the final chapter.

For the very first step towards enhancing capacity building in fire management at regional level the editors acknowledge the contributions by a large number of authors. Finances for this book have been provided by the German Foreign Office and the UN International Strategy for Disaster Reduction (ISDR). The handbook is available at reasonable costs for those working or being trained in wildland fire management in the subcontinent.

This handbook is a contribution to the New Partnership for Africa's Development (NEPAD).

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1

INTRODUCTION

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1.1 HOMINID HEARTH: AN INTRODUCTION TO THE HUMAN HISTORY OF FIRE IN AFRICA

Africa is a fire continent. Even discounting the Sahara – a desert nearly as large as Europe – Africa sparkles with more routine fire than any other landmass. The significance of African fire, however, derives not only from its extent but its antiquity. Here anthropogenic fire originated and has resided longer than anywhere else. These two facts, its antiquity and its size, make African fire equally unique and undeniable. Its fires calibrate wonderfully Africa's natural history

Begin with geography. Fire flourishes because most of sub-Sahara Africa has an environment to sustain it. There exists, first, a chronic rhythm of wetting and drying. Seasonality flows a cadence of rainfall, not temperature. Wet seasons grow fuels; dry ones ready them for burning. Across this annual rhythm, longer waves of drought and

deluge rise and fall. The formula is ideal for fire, and the onset of the rains will typically bring scattered thunderstorms laden with dry lightning. Long before humans arrived, fire thrived, and will continue to do so – bar only the driest and wettest sites – if people leave.

Other features of the African scene encourage burning. Africa is the highest of the vegetated continents, which helps explain its extraordinary mineral wealth (its exposed kimberlite pipes and deep copper deposits, for example), but that same process of deep erosion and leaching has left much of the continent with impauperate soils. Some volcanism along the Rift Valley has renewed nutrients locally and river floodplains receive regular loads of fresh alluvium; but most of the soil, by the standards of the northern hemisphere, is relatively indigent. Anything that can move precious nutrients through the biota will claim an important role in nature's economy. That fire does.

Equally, Africa's fauna matter enormously. Nearly 75% of the continent's megafauna survived the great Pleistocene kill-off, far more than any other continent. These animals profoundly shape the flora, which is to say, the fuels on which fire must feed. In fact, the two combustions compete – the slow-combustion of respiration with the fast-combustion of fire, metabolising animals with the flames of burning biomass. The interactions are difficult to track precisely, for animals, plants and fire make a kind of ecological three-body problem that can only be understood approximately and locally. In general terms, the relationship depends on whether the land is prone to fire or not. If not, the animals are often vital in stirring the fuels into forms that can burn – for example, bashing over trees, opening canopies and stirring the surface vegetation. If the beasts vanish, the conditions for burning may vanish with them. If, however, the land is fire-prone, then removing megafauna can liberate fuels. Grasses and scrub that would otherwise be eaten can be burned. The survival of its megafauna has meant, overall, an increase in the land subject to fire. Probably the striking edges that abruptly separate burning *veld* from unburnable forests are a border erected by fauna as well as flame.

The biota of sub-Saharan Africa, then, has long adapted to the burdens of drought, grazing, browsing, impauperate soils and, in most sites, fire. Its flora tends to exhibit a suite of traits that help accommodate this suite of stresses. Such a biota can respond readily to more fire, or more properly to a shift in fire's regime, for the issue is not whether fire, stark and singular, comes or not, but what patterns its arrival and departure assume.

Its *regime* describes fire's typical size, seasonal timing, frequency, intensity – the patches and pulses by which it manifests itself. (A regime is a statistical concept. Individual fires are to regimes as storms are to climate.) In fire-prone lands, these characteristics result mostly from the configuration of ignition. And that is why hominids matter, and why Africa can justly claim special standing for the insights it provides regarding the meaning of the human species monopoly over fire.

The capture of fire by early humans marks a profound moment in the natural history of the Earth. So fundamental is combustion to life on the planet that the ability to apply flame more or less at will conveys an unprecedented power on any species that holds a firestick. The history of humanity as an ecological agent can be tracked by our ability to expand the dominion of fire and our willingness to apply fire for whatever purposes we conceive.

Probably the earliest hominids could carry and nurture fire but not kindle it on command. *Homo erectus*, for instance, could likely tend fires seized from natural sources or acquired from other bands of hominids. But the instruments for starting fires, such as striking flints, abrading wood and twirling drills, all derive from a tool-kit not developed until later times. With *Homo sapiens*, however, the capacity to combust becomes as common as the ability to drill holes in bone or knap obsidian into spearpoints. From this instant on, the dominant source of earthly ignition has been anthropogenic.

The ability to create spark is, nonetheless, not synonymous with the ability to propagate fire.

The human firestick is only as powerful as its setting. If the land is not ready to burn, no shower of sparks, however torrential, will set it aflame. A match won't set an empty fireplace ablaze. What matters is the receptivity of the land. If it is fire-prone, then people can easily assume control over its regimes. The reality is that anthropogenic fire competes against natural fire, usually by burning early in the dry season, or otherwise changing the timing of ignition. Its power amplifies where the megafaunal population has thinned and thereby liberates more fuels to feed the flame.

Still, even in a generally fire-favoured continent like Africa, this leaves vast patches of land untouched by flame of any kind. For humans to seize the commanding heights of nature's economy, they need to control fuels as they do ignition. This, from the perspective of fire history, is the meaning of agriculture. Farmers and herders could apply axes and mauls, tooth and hoof, to crunch, fell, grow, dry out and restack biotas so that they might burn when they would not, unaltered, do so. More fuel means more fire.

As agriculture began its slow 6000-year colonisation of Africa, it refashioned fire regimes in two ways. First, it remade many aboriginal fire regimes. Fire's pulses beat to new rhythms, fire's patches to new purposes. Agriculture disciplined flame into the social order of farming and herding, while crowding hunters and foragers trekked to more marginal sites. The fire options were not simply between nature and humanity, but between nature and several variants of anthropogenic burning. Second, agriculture pushed fire into places like shade forests that it had previously been unable to penetrate. The expansion of

Bantu-speakers is the best-known and most pervasive example, and since that colonisation was accompanied by iron hoes and axes, it hauled across these landscapes the forge-fires of metallurgy (with their inexhaustible craving for woody fuel). The overall geography of African fire expanded enormously, and it altered its character. African fire became increasingly obedient to the whim and will of human culture.

The character of cultivation derived from the catalytic power of flame. Few sites allowed for sedentary agriculture – and those tended to cluster along rivers or deltas where water could take the place of fire as a disturber, as a means to purge and promote. Wet epochs could make burning difficult; drought could starve fire of its fuels. The solution was to move through the landscape, to rotate the farm through the countryside, to allow fuels to regrow and then reburn. In this way, people could exploit the basic principles of fire ecology, which underwrote this system of fire-fallow farming. For a year, the site was fumigated and fertilised and open to the cultivation of exotic plants. Within two years, the indigenous biota would reclaim the site, choking it with weeds and (from an agricultural perspective) vermin. The abandoned plot would resprout, until, at some time in the future, it would be slashed, dried and burned again. The celebrated *chitemene* system common in southern Africa is a textbook example.

Yet limits remained. Not every biota could be minced into combustibles and burned when convenient for agriculturalists. Megafauna competed with domesticated livestock. So did microfauna in the form of diseases that plagued people and their servant species, notably the tsetse fly and

triplanosomes, which for long stalled settlement. And while fuels swelled with the hoofs and axes of agriculture, they remained bounded by the larger properties of soil and climate. One could not convert more biomass into fuel than nature, even assisted, could grow. The realm of fuels spread out, but never transcended the green shackles of its ecological roots.

One could also add to this broth of historical factors the commercial isolation of Africa, which buffered it against stimulants from the outside world. Sahara sands shrank commerce northward to a trickle. Rapids and falls shut down river traffic. Good harbours were rare, and long-range maritime shipping sparse, save along the eastern flank, where Swahili settlements sprang up to integrate parts of Africa into the commerce of the Indian Ocean and the *ecumene* of commercial Islam. But until far-voyaging Europeans ventured along the Atlantic coast, there was little prod elsewhere. The geography of African fire responded to the internal dynamics of migrating peoples, particularly swiddeners from West Africa and pastoralists pushing through Ethiopia, both pressing southward. Even after European outposts dotted the littoral, they remained trading factories. For 400 years Europeans clung to the coast like barnacles. They traded; they didn't – couldn't – move inland; diseases alone stalled any serious demographic surge. Their impact was indirect.

When Europeans finally did push inward, they did not colonise by massive immigration, save spottily in far South Africa. The principles that governed African fire ecology endured. Francis Bacon's dictum held as true for fire as for other technologies: Nature to be commanded had to be

obeyed. Kingdoms rose and fell with the same kind of patch dynamics that ruled fire ecology. What changed were the particular expressions of those principles as populations became scrambled and trade routes fell under new jurisdictions. Even the horrendous collapse of native societies in the latter 19th century – the crash of populations (of people, livestock, wild ungulates) precipitated by the spread of *rinderpest* and market hunting, the crushing long drought connected to millennial ENSO events, the pathological disruption wrought by the final spasms of slaving, warring and colonial conquest – these remained within the larger span of African experience. The ecological aftershocks, while unique in detail and horrific in extent, were broadly predictable. They would move the circle of ecological transactions in and out, like biotic bellows. But the basics endured, and the ecological circle of fire remained unbroken.

It snapped only when European imperialism became the vector for industrialisation. From the vantage point of fire history, industrialisation refers to the wholesale combustion of fossil biomass. The industrial revolution fundamentally reconfigured human firepower by expanding stupendously the stocks of combustibles. For practical purposes they became unbounded, and the ability of anthropogenic burning to affect the landscape, both directly and indirectly, promised to shatter the confining rings and rhythms of ecology. Industrial fire not only competes against other combustion, but – at least momentarily – transcends it.

The general properties of industrial fire are poorly understood. But the following features

seem universally true: Where fire exists as a “tool”, industrial combustion can readily substitute, and does. Where fire exists within an agricultural context, a resort to fossil fallow eventually shoves aside the old practices of creating fuels out of living fallow and then burning them. In fully industrialised nations, free-burning fire survives largely in nature reserves or, temporarily, on abandoned agricultural fields. Globally, the Earth is dividing into two great combustion realms: one dominated by the burning of living biomass, the other by the burning of fossil biomass. Few lands hold both, or do so metastably.

With scant exceptions, sub-Sahara Africa belongs with the first group. It persists as a place of open flame sustained by aboriginal fire practices or fire-fallow agriculture. A few enclaves have escaped, of which portions of South Africa, rich in coal, are primary. How Africa might industrialise is unclear. Around the earth, there seems to exist a pyric equivalent to the demographic transition: a troubled period when old fire practices live on and new ones flourish, causing a massive swell in the overall population of fires. Uncontained fires breed like flies. Once docile fires turn feral, fires seem to overwhelm the land. Eventually this passes. Industrial fire practices substitute for their predecessors; the fire load declines; combustion throbs within machines, outside direct contact with the land. Society absorbs and contains combustion as ancient organisms did respiration. But the era of exploding fires often brands itself into memory, especially for elites. That industrialisation coincided historically with an era of colonial conservation no doubt sharpened the critique of open burning.

All this is happening to Africa, though slowly and spottily. Countries like Nigeria hold immense reserves of petroleum, yet export those fuels and continue to rely on open flame for daily life. That disconnect is characteristic. Rural fire is everywhere and difficult to extinguish. Even in places like Europe, which lack a natural basis for fire, it loosens its grip reluctantly. In the United States it took over 60 years to unshackle the most fire-flushed rural landscapes. One complicating problem in Africa is that agriculture cannot easily move into a fossil-fallow regime. Besides, rural fire is not ultimately a fire problem but a condition of rural life. To eliminate it, Africa will have to become something very different from what it is now. A reform in fire practices can only accompany a general reformation of society.

Even so, fire will flourish. Favourable geographic conditions will endure; industrial peoples, typically urban, tend to reserve swathes of land as nature reserves, and on these, in Africa, fire will persist; and the abolition of fire is, in any event, an unnecessary, problematic and ironic ambition. Fire will endure in Africa simply because Africans will wish it to. The real issue is what kind of fire they want, to what ends they desire it and by what means they might allow such fires to do what fire ceremonies universally proclaim fire to do – to promote the good and purge the bad. The fire in the hominid hearth is unlikely to expire soon.

1.2 FIRE ECOLOGY IN AFRICAN BIOMES

Besides human activities related to urban living and agricultural production, fire is the most widespread ecological disturbance in the world. From

1.1



the arctic boreal forests to the tropical grasslands and savannas of the world, fire consumes enormous quantities of plant biomass. It has been estimated that 2700–6800 million tons of plant carbon are consumed annually through the burning of savanna vegetation and through its use in shifting agriculture. It is concluded that human beings have used fire for over a million years, and in Africa fire has extended the grasslands and savannas at the expense of evergreen forests. This reinforces the fundamental conclusion that fire is a general and influential ecological phenomenon throughout the world (Bond & Van Wilgen, 1996) and cannot be ignored when considering the management of rangeland ecosystems for both domestic livestock and wildlife purposes.

Africa is referred to as the *Fire Continent* (Komarek, 1971) because of the widespread occurrence of biomass burning, particularly in the savanna and grassland biomes. The capacity of Africa to support fire stems from the fact that it is highly prone to lightning storms and has an ideal fire climate comprising dry and wet periods. It also has the most extensive area of tropical savanna in the world, which is characterised by a grassy understorey that becomes extremely

inflammable during the dry season (see Figure 1.2).

As a result of the aforementioned aspects, fire is regarded as a natural ecological factor of the environment that has been occurring since time immemorial in the savanna and grassland areas of Africa. Its use in the management of vegetation, for both domestic livestock systems and in wildlife conservation, is widely recognised (Tainton, 1999) and is best summed up by Phillips (1965) as being “a bad master but a good servant”.

The role of fire in Africa, south of the Sahara, ranges from “a rare feature” in both the driest regions (e.g. in the arid Karoo biome and semi-deserts) and in the wettest regions (e.g. in wet montane forests), to a yearly or two-yearly occurrence (e.g. in moist montane “dynamic” grasslands). In some biomes, human-caused fire is the most important factor affecting plant communities (e.g. in savannas of West Africa), while in others lightning fires are more common (e.g. in humid Equatorial areas: Mounkeila, 1984; Swaine, 1992). In most of the other biomes in sub-Saharan Africa, fires are caused mostly by lightning and anthropogenic sources. In some biomes the frequency of wildfires is alarming and widespread, such as in the forests and savannas of West African countries. In lesser-developed countries south of the Sahara, most fires are initiated through prescribed burning programmes that are designed to meet range and wildlife management objectives (Mounkeila, 1984).

In the fynbos biome of the Cape regions in South Africa, fire frequency ranges mostly from 10 to 40 years, and most fires occur during the summer, at least in the winter rainfall area of the Western Cape. In the all-year rainfall area of the

Figure 1.1. Savanna fire in progress (Photo: J.G. Goldammer).

1.2



Southern Cape and Tsitsikamma, more fires occur in winter, during bergwind conditions (Edwards, 1984). Further north, across the Cape mountain ranges, there is little evidence of regular occurrence of extensive natural fires. The most likely fires to occur in the arid Karoo region are lightning fires, particularly in the grassy transi-

tional mountainous areas of this biome. Elsewhere in the Karoo, fires are rare (Edwards, 1984).

In most areas of the summer rainfall area south of the Sahara, particularly in the vast grassland-savanna biomes, fires are mainly caused by lightning and humans, and these fires are far more

1.3



Figure 1.2. The distribution of tropical savanna and forest vegetation types in the world (adapted from Bartholomew 1987).
Figure 1.3. Fire in progress in fynbos vegetation (Photo: D. Richardson).

frequent than in fynbos. Three years of protection from fire, grazing and other forms of botanical composition. In arid grassland and savanna, grazing alone may suffice to maintain the grass component, but under natural conditions fire is necessary to maintain the vigour of moist, sour grasslands (Edwards, 1984). In the savanna areas of Africa, fire is recognised as having an important ecological role in the development and maintenance of productive and stable savanna communities. Nevertheless, except for wildlife areas, the general attitude regarding its practical use tends to be negative; controlled burning is applied as a last resort (Trollope, 1984).

In mixed evergreen forests, fire is generally regarded as part of the African landscape, but not as part of the ecology. However, several scientists have reported on the role of fire in the dynamics of forests. Fire behaviour determines the location pattern of forest in the landscape. Forest species vary in their response to fire, and some forest species depend on fire for regeneration (Geldenhuys, 1994). In general, frequent fires will destroy mixed evergreen forest, but the occasional fire rejuvenates forest. In any one area one could relate forest with very low fire frequencies and grassland with very high (sometimes annual) fire frequencies, with woodland and shrubland having intermediate long to short fire frequencies.

1.3 FIRE MANAGEMENT IN AGRICULTURE, FORESTRY AND NATURE CONSERVATION

Land use in Africa is changing rapidly and organised agriculture in particular is replacing the rural,

traditional way of living and fire-use fast, particularly in southern Africa. More land is also being set aside for nature reserves, and while the addition of land for timber plantations may at present be restricted to a few southern African countries, new forestry regions may be created in parts of eastern Africa in the future, as more and more suitable sites for growing trees in plantation-form are identified. The existing two million hectares of land in Africa south of the Sahara under man-made forests, could easily be doubled or tripled given sufficient incentive from the industrialised world.

As natural vegetation fuels are manipulated to different forms, with sometimes drastic increases in fire hazard, it is important that fire managers identify and quantify these changes in fuel conditions to meet the challenges of subsequent increases in wildfires. Changing grazing patterns can in other words create significant variations in fire frequency while managed savanna grassland within nature reserves can change significantly in fire hazard status as new management regimes replace older ones – e.g. the move away from a specific prescribed burning application system to a more “laissez-faire” (“not interfering”) policy, and eventually maybe arriving at a combination of the two regimes. In plantation forestry, fuels change drastically after each silvicultural treatment (e.g. after pruning, thinning or clearfelling), as well as with age. A complicated fuel mosaic is formed which is difficult to track over time, but which can create extremely hazardous conditions overnight. Fire managers are thus increasingly faced with rapidly changing fire hazard conditions that need a flexible fire



protection approach, as well as well-trained fire managers to satisfy these dynamic demands.

Global warming – and subsequent extreme weather conditions – are making the fire managers' tasks even more difficult in the field of fuel management and fire protection, and more and more advanced training will be required for all types of fire managers to meet these challenges. Fire managers of all disciplines, including professional firefighters, farmers, foresters and nature conservators, are now realising that they lack formal training and experience to cope with these new situations, and short-term solutions – such as interim training courses – are already, in many

cases, arranged as a matter of urgency to reduce these serious shortcomings. Only incomplete statistics are available to underline the importance of fire management training, but a recent survey in the southern African forestry industry has revealed that up to 10% of wildfire damage was caused by prescribed burning of fire breaks "going wrong" – a situation that obviously needs serious attention and an urgent re-evaluation of formal training required at different levels.

Another field where experienced managers are needed is in the assessment of the impact of wildfires. It is particularly in planted forests that a lack of skilled managers exists. The forestry

Figure 1.4. *Aloe ferox* leaves burning (Photo: W.S.W. Trollope).

industry is looking for trained foresters that can minimise timber losses, prioritise tree exploitation after a wildfire and determine the burned site's nutrient requirements for re-establishment purposes. Sometimes a threat of serious soil erosion and weed regeneration can exacerbate matters after wildfires, and Africa needs experienced managers to cope with these issues. Well-trained, experienced, fire management educators are also urgently required to provide suitable training to fire specialists. At present, suitable fire management instructors are so few it is difficult to provide adequate training at both undergraduate and postgraduate levels.

The conducting of fire-related research in Africa is totally inadequate and in most countries on the continent is almost non-existent. To ensure the correct use of fire with the current and future changes in land use it is essential to have a well planned research programme for developing and providing the necessary technology for the sustainable use of natural resources of Africa.

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2

FIRE ECOLOGY: CHARACTERISTICS OF SOME IMPORTANT BIOMES OF SUB-SAHARA AFRICA

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2.1 FYNBOS OF THE WESTERN AND SOUTHERN CAPE REGIONS

The shrublands of both the southern and south-western tip of Africa are very different from the grass or forest-dominated landscapes of the rest of the sub-continent. Like many other shrubland biomes of the world, they occur in climates with substantial winter rainfall. The fynbos biome is a fire-prone shrubland in the wetter areas along the coast, and in the mountains of the south-west. The Succulent Karoo biome is an arid shrubland of the intermontane valleys and the interior, dominated by stem and leaf succulents. Plant cover is too sparse to support fires in most areas of this biome.

This section briefly introduces the reader to the distinctive growth forms of the fynbos biome, its main vegetation types, the distinctive flora of the region and the importance of fire in system functioning.



2.1

Fynbos, a vernacular term for fine-leaved shrubs, is vegetation dominated by evergreen shrubs. These include small-leaved ericoid shrubs, including many species of Ericaceae, but also many shrubs in other families, including several endemic families such as the Bruniaceae and Peneaceae. Mixed with the ericoid shrubs are taller proteoid shrubs, dominated by members of the Proteaceae. The most distinctive of features of fynbos is,

Figure 2.1. Typical fynbos in mountains of the Western Cape Province of South Africa. Note the sharp biomass and cover height contrast between lower and upper slope vegetation (Photo: C. de Ronde).

however, the universal presence of Restionaceae. These are wiry, evergreen, grass-like plants. Rare elsewhere in Africa, they are common, often dominant, elements of the fynbos understory. Fynbos-like heathlands occur in the high mountains of Africa and similar vegetation is widespread in Australia. However, unlike Australia, where eucalypts can form a woodland overstorey, native tall trees are extremely rare in the fynbos biome.

Two other major vegetation types are included in the fynbos biome. These are renosterveld and strandveld. Renosterveld is also an evergreen, fire-prone shrubland. However, it is dominated by shrubs of the daisy family (Asteraceae), especially *Elytropappus rhinocerotis*, the renosterbos (rhino bush). Proteoids are usually absent and so are the distinctive restios, characteristic of fynbos. In renosterveld, restios are replaced by grasses, which become increasingly prominent as summer rainfall increases. Strandveld is a mix of thickets made up of broad-leaved shrubs and small trees, fynbos and renosterveld. These broad-leaved elements also occur in fire-excluding thickets and scrub forests in summer rainfall regions. They are not flammable, have fleshy fruits (rare in fynbos) and exclude low intensity burns.

2.1.1 Floristic Elements

2.1.1.1 Fynbos

Fynbos covers an extremely broad climatic range from ca. 250 mm rainfall per year in the lowlands to more than 3000 mm, the highest rainfall in South Africa, in the mountains of the Western Cape. Rainfall is concentrated in the winter months in the west, gradually changing to non-seasonal in the east. Temperatures are milder at lower

altitudes, but freezing temperatures – and even occasional winter snowfalls – occur at higher altitudes in the mountains.

The topography varies from rugged mountains to flat sandy coastal plains. The mountains are predominantly quartzites producing mostly shallow, sandy, infertile soils low in phosphorus. Fynbos also occurs on the coastal forelands in locally extensive areas of acid and alkaline sands. It dominates on limestone outcrops, especially in the south. Nutrient-poor soils are closely correlated with the distribution limits of fynbos. However, it is not clear whether this is a cause of fynbos presence, or a consequence of long occupancy of a site by vegetation with very poor litter quality. Closed forest occurs adjacent to fynbos in some landscapes and grows on similar soils. Though forest trees are probably unable to survive on the shallower rocky soils, they can tolerate soils of relatively low nutrient status.

Fynbos shows remarkably little structural variation, given the wide range of moisture and soil conditions under which it is found. This is particularly surprising because of the very high species diversity for which the Cape is famous. Indeed, the visitor is struck by the remarkable convergence of different families and genera into a handful of common plant forms. Some 85% of the species fall into just six plant types. Cowling et al. (1997) defined these as proteoids, ericoids, restioids, geophytes, “fire ephemerals” and “obligate sprouters”. Proteoids are the tallest (1.5–5.0 m). Members of the Proteaceae, usually with broad flat leaves, form the overstorey of many fynbos communities at low to medium altitudes. Ericoids are smaller shrubs (0.5–2 m)

with small, narrow leaves. Most fynbos species fall into this category. Restioids include not only the Restionaceae, but also grasses, sedges and, indeed, some members of the Iridaceae, such as *Bobartia* spp.. Unlike the grasses of the summer rainfall regions, fynbos grasses and sedges are mostly wiry and evergreen, like the restios. Geophytes are a cryptic element of the vegetation since many species only flower intermittently after fire. Fire ephemerals include annuals and short-lived herbs that appear briefly after fire. Also included are fire-stimulated shrubs, including many of the legume species. Finally, “obligate sprouters” are yet another shrub growth-form. They have broad evergreen sclerophyll leaves but, unlike the proteoids, they differ in their phylogenetic affinities being related to forest species. They also differ in life history characteristics (all sprout after burning – hence “obligate sprouter”) and have no obvious adaptations to fire.

There have been several attempts to define variation in fynbos across the biome. For example, “coastal fynbos” was once distinguished from “mountain” fynbos. However divisions based on vegetation structure, as opposed to the habitats in which they grow, are not consistent with these earlier classifications. Nevertheless, there are some fairly consistent patterns in the distribution of different fynbos elements along gradients of rainfall amounts and seasonality. Protea-dominated communities are most common on the deeper soils on the low to mid-slopes of mountains and coastal lowlands. Ericoid shrubs with few proteas dominate at higher altitudes. Restios become very prominent on warmer, drier, mountain slopes,

but also, curiously, in wetlands too. At the arid extreme of fynbos, restios and proteas are rare and members of the Asteraceae become more prominent among ericoid shrubs. Rainfall seasonality also influences fynbos structure. As summer rainfall increases towards the east, grasses begin to replace restios, eventually producing “grassy fynbos” in the mountains of the Eastern Cape. The fynbos of the wet mountain slopes of the Outeniquas and the Tsitsikamma mountains is also distinctive, supporting a tall (> 4m) dense fynbos in which members of the Bruniaceae with small, linear leaves are prominent.

Despite the structural uniformity, fynbos is renowned for its floristic diversity. The fynbos biome is more or less consistent within the Cape Floristic Region, one of the world’s floristic “hotspots” of diversity. The fynbos biome contains some 7300 species, of which about 80% are endemic (found nowhere else in the world). The uniqueness of the flora is a major consideration in its management.

2.1.1.2 Renosterveld

Renosterveld was once an important component of the fynbos biome, occupying ca. 20 000 km² on the more clay-rich soils of the coastal forelands and inland valleys. It is common to find abrupt transitions from fynbos on the sandy soils of quartzite mountain ranges to clay rich soils derived from shales on the lower slopes. Renosterveld has been radically transformed by agriculture, since much of its former area was suitable for crop farming. Only small pockets remain in the extensive wheatlands of the north-western and

southern coastal forelands, with more extensive areas in the steeper terrain on mountain foothills.

Renosterveld is dominated by grey-leaved shrubs of the daisy family, most prominent of which is the renosterbos, *Elytropappus rhinocerotis*. The understorey has varying amounts of grass, with *Themeda triandra* becoming prominent in the east as summer rainfall increases. Though it can have a somewhat drab, monotonous aspect, especially in mid-summer, renosterveld is rich in geophytes. After a burn, these can produce a spectacular flowering display.

Despite its extensive geographic range, renosterveld is still poorly studied relative to fynbos.

2.1.1.3 Strandveld

Strandveld differs from fynbos and renosterveld in that its dominant elements are fire-avoiding. These are broad-leaved evergreen shrubs and small trees forming patches of thicket or scrub forest. The broad-leaved thicket intermingles with elements of fynbos and renosterveld. Strandveld, as the name implies, typically occurs as a narrow band along the coast varying from a few metres to a kilometre or more. Soils are usually calcium richer, with more phosphorus present than in both fynbos and renosterveld soils. Unlike fynbos and renosterveld, the broad-leaved shrubs and trees thrive best without fire. Fruits are usually fleshy and recruit under the shade or in gaps in the absence of fire. With the sea behind it, strandveld is less exposed to fire than other elements in the biome. Patches of strandveld-like vegetation also occur away from the coast, such as in the Agter-Cederberg, in deep cracks

and ravines in extremely rocky terrain where trees are protected from fire and, perhaps, obtain runoff from the rocks.

2.1.2 Role of Fire

2.1.2.1 Fynbos

The fire ecology of fynbos has been well studied, especially from the 1980s, yet there are still surprises and new discoveries to be made. In the early years of the 20th century, fire was seen as a damaging influence on the biota by most influential biologists of the time. This view began changing by the 1950s and there is now widespread recognition that a great many fynbos plant species require fire to complete their life cycles.

Burning triggers different stages in plant life cycles, including flowering, seed dispersal and seed germination in fire-dependent plants. Perennial grasses and herbs, including orchids, lilies and other bulb-plants, flower prolifically after they have been burnt, often as a facultative response to higher light, water and nutrient availability. The fire lilies, *Cyrtanthus* spp., flower only after fire. In these and other species, flowering is stimulated by constituents of smoke. The seeds of fire-flowering species typically germinate readily. However, seeds only become available after a burn, so that population growth is episodic and stimulated by fire.

Burning stimulates seed release from species with serotinous cone-like structures, which store seeds on the plant for years between fires. Serotiny is common in shrubs and small trees among both conifers (*Widdringtonia*) and diverse groups of flowering plants in fynbos. Many species in the Proteaceae are serotinous (species of

Protea, *Leucadendron* and *Aulax*) and often dominate fynbos stands. Other families with serotinous members include Bruniaceae, Asteraceae (*Phae-nocoma*, *Oedera*) and even a species of *Erica* (*E. sessiliflora*). Some Restionaceae also retain seeds for long periods and may be weakly serotinous. The seeds of serotinous species usually germinate readily after release from the cones.

Many species of fynbos plants accumulate seeds in dormant seedbanks in the soil. Most have specialised germination cues linked to fire. Heat-stimulated seed germination is common in many legumes (e.g. *Aspalathus* spp.), and in other groups with hard seed coats (e.g. *Phyllica*, in the Rhamnaceae). Thick seed coats prevent imbibition of water, until cracked by the heat of a fire. Smoke-stimulated seed germination has recently been reported for many species of fynbos shrubs and herbs. It is particularly common among plants with small seeds without hard seed coats. Smoke-stimulated seed germination has now also been reported in fire-prone shrublands of Australia and California and also in some grass-land species. Nitrogen dioxide, released in large quantities in smoke, cues seed germination in *Emmenanthe pendulifera*, a Californian chaparral annual, but we do not know what constituent of smoke cues germination in any fynbos species. The least understood group of fire-stimulated plants are those with seeds dispersed by ants. Hundreds of fynbos species have seeds with small elaiosomes attached. These are attractive to ants and are buried by them in their nests. Most of these species germinate only after fire, but attempts to germinate such seeds with heat or smoke treatments, have so far, usually failed.

Species with fire-stimulated flowering, seed release or seed germination, require fire for their populations to grow. Fynbos also includes species with no fire-related recruitment cue and these species are able to expand their populations in the absence of burning. Broad-leaved shrubs and trees of forest affinities are prominent among this category, and population growth is favoured by long periods without burning.

Vegetative features of plants affect tolerance to burning. Thick bark and the ability to resprout enable many plants to survive burning. Neither feature is necessarily a fire adaptation. Sprouting is a common fire survival mechanism, either from the rootstock, or from branches above the ground. Some species possess large swollen burls or lignotubers, which are thought to act as bud banks or storage reserves. Paradoxically, many fynbos shrubs and restios cannot resprout and are killed by fire. These non-sprouting plants often have higher seed production and higher seedling growth than related sprouting species. Non-sprouting shrubs often dominate fynbos stands and require fire to stimulate recruitment of seedlings. Non-sprouting species are particularly prone to local extinction if recruitment fails after burning.

Stimulated species suggest that fire was a natural phenomenon in this vegetation but we have no information on how many species cannot flower or germinate without fire. The dominant renosterveld shrub, *Elytropappus rhinocerotis*, has variable sprouting behaviour across its wide geographic range, sprouting after some fires (some geographic areas) but not in others. Seedlings emerge in the first year after a burn, but the species can also invade open patches in the absence

of fire. Renosterveld is now highly fragmented by agricultural activity (> 90% has been lost to the plough) and burning is actively discouraged in many of the remnants because of the risk to adjacent agricultural land. We need to know more about the fire requirements of renosterveld species if we wish to conserve this rich flora.

The response of strandveld to burning is even less understood than renosterveld. The dominant broad-leaf shrubs all sprout after burning but their seedlings are fire avoiders. Frequent, intense fires in strandveld are likely to promote the fynbos elements at the expense of the broad-leaf shrubs. Strandveld is the least likely of the biome components to contain species with an obligate dependance on fire.

2.1.2.3 Above-Ground Biomass

Above-ground biomass of fynbos shrublands, ranges from 10 tons/ha to about 40 tons/ha in mature stands with post-burn ages > 15 years. Biomass shows no consistent trend across rainfall gradients, and some of the highest rainfall areas support low biomass. Biomass varies greatly within sites, especially in proteoid stands. Where the proteoid overstorey is dominated by non-sprouting species, successive generations can have highly variable biomass because of regeneration failure after one fire or spectacular success after another. The most consistent feature of stand productivity is that above-ground biomass increases rapidly after a burn for three or four years, slowing thereafter. Decomposition is slow, and old stands of fynbos carry large loads of highly flammable standing dead litter. Fire is of major importance in recycling nutrients.

Renosterveld generally has a much more uniform structure than fynbos, and shows much less variation due to recruitment variability. Biomass of one stand was estimated as 11 tons/ha.

Strandveld has a highly variable structure depending on the frequency of broad-leaf shrubs and trees. At the mesic end, strandveld merges into forest. Biomass of fuel elements < 6 mm in diameter was 42 tons/ha in a Cape forest.

2.2 AFRO-ALPINE AND SUB AFRO-ALPINE VEGETATION

The characteristic plant species in this vegetation type include small trees, giant herbs, shrubs, suffrutescents and herbs, such as *Erica arborea*, *Philippia trimera*, *Kniphofia* spp., *Helichrysum* spp., *Bartsia petitiata*, *Alchemilla* spp., *Crassula* spp., and giant *Lobelia* spp. Grasses are mainly species of *Festuca*, *Poa* and *Agrostis*.

The vegetation consists of areas mostly at an altitude higher than 3200 m, i.e. on mountain peaks and slopes of the highest mountains in the country. The rocks are volcanic, being mostly basalt and trachyte. Moisture is not limiting in these high altitude regions, since the mountains attract much rain, and since basaltic and trachyte bedrocks restrict internal drainage. Temperatures are low, with night temperatures falling below freezing point. The soil is shallow, but very rich, with an abundance of undecomposed organic matter owing to low temperature regimes.

Livestock grazing and cultivation usually involve fire, and these human activities threaten existence of the vegetation. Undecomposed organic matter of *Erica arborea* and *Philippia trimera*

shrubs are often destroyed by human-induced fire, and they regenerate soon after a fire was experienced. Uncontrolled grazing by livestock is being intensified, and barley cultivation has encroached on the steeper and better-drained lower parts where this vegetation occurs. The Afro-alpine vegetation of the northern mountains has been more affected by fire than the southern mountains.

The vegetation occurs in a fragile environment, with unique climate of “summer every day and winter every night”. It represents the upper catchment for many important rivers. Destruction of the vegetation can result in extinction of endemic plants and animals.

Two of the most famous parks of Ethiopia – Semien Mountain Park (SMP) in the north and Bale Mountains Park (BMP) in the south – are located here. The SMP was designated as a World Heritage Site in 1978, and contains the endemics walya ibex, Semien jackal and gelada baboon, as well as leopard, caracal, wildcat, bushbuck and ca. 400 bird species. The BMP contains 46 mammals, including the endemics, mountain nyala, Semien jackal, Menelik’s bushbuck and others, such as leopard and olive baboon. Approximately 160 birds species occur in BMP (including 14 of the 24 endemics), including the endemic giant mole rat (Teketay, 2000).

2.3 GRASSLANDS

2.3.1 Montane Grasslands of Southern Africa

In southern Africa, the Afromontane region is

centered in the Lesotho and KwaZulu-Natal Drakensberg with extensions north and south along the Great Escarpment (Cowling & Hilton-Taylor, 1997). The dominant vegetation is grassland, usually with a mixture of temperate C_3 and tropical C_4 species (Vogel et al., 1978). The extent of the grassland is strongly determined by climatic variables, with fire and grazing exerting considerable influence over the boundaries of the grassland biome (Cowling & Hilton-Taylor, 1997). These grassland areas are relatively cool, with a moderate to high summer rainfall (above 600 mm). Winters are relatively dry and cold, with snow occurring at the higher altitudes. Annual production of these grasslands ranges from 2.5 to 3.0 tons/ha/year.

Two main types of grassland may be distinguished:

- **Climatic climax grassland** where succession does not normally proceed beyond the grassland stage because the climate is too cold to permit the development of woody communities, even in the absence of fire. These grasslands are also referred to as “true” grasslands (Acocks, 1988). They are short, sour grasslands dominated by moisture-loving species such as *Trachypogon spicatus*, *Diheteropogon filifolius* and *Cymbopogon marginatus*. Temperate species are also important and include species of *Festuca* and *Merxmüllera* as well as *Pentachistis micorphylla*, *Helictotrichon hirtulum*, *Koeleria cristata*, *Poa binata* and *Bromus firmior*. Some fynbos shrubs also occur here, such as *Passerina montana* and species of *Erica* and *Cliffortia* (Acocks, 1988).

2.2



Trees are rare in this region, and tree growth is restricted to the Highveld in southern Africa as a result of the dry and extremely frosty winters. However, there is insufficient evidence that frost is primarily responsible for the almost total absence of larger woody plants (White, 1983).

Acoks (1988) recognised ten veld types of high altitude grasslands, which are distinguished mainly by the different proportions of dominant species that occur. In degraded climatic climax grassland *Themeda triandra* is replaced by pioneer grasses such as *Aristida* spp. and *Chloris virgata*, as well as invasive shrubs like *Chrysocoma tenuifolia* and annual weeds (*Tribulus terrestris*).

- **Fire climax grasslands** occur where the climate will permit succession to proceed

2.3 a



2.3 b



beyond the grassland stage into shrubland or forest, but which are maintained as grassland by biotic factors such as fire and grazing (Huntley, 1984). These grasslands are also referred to as “secondary” grasslands (White, 1983), or “false” grasslands (Acoks, 1988). Common species of fire climax grasslands in the forest belt are *Themeda triandra*, *Elionurus argenteus*, *Loudetia simplex* and *Monocymbium cerasiiforme*. In the Ericaceous and Afro-alpine belts, they are replaced by species of *Agrostis*, *Deschampia*, *Hyparrhenia* and *Setaria*. (White, 1983). Degradation of these grassland areas leads to the invasion of xerophytic fynbos shrubs such as *Felicia* spp.

Figure 2.2. Fire in progress in montane grassland of the Drakensberg Mountains (Photo: T.M. Everson).

Figure 2.3 a and b. Cured savanna grassland in the Kruger National Park, South Africa, during the dry winter season. The upper photograph shows an observation plot burned annually, the lower photograph shows a plot with same site characteristics excluded from fire for 35 years (Photos: J.G. Goldammer).

When secondary montane grassland is protected from fire for several years, it is eventually invaded by forest-precursor shrubs such as *Leucosidea sericea* and *Buddleia salviifolia*, which form a dense thicket. Isolated patches of primary forest dominated by *Podocarpus* species, occur in refuge sites where fires are absent, or infrequent.

2.3.2 Kalahari Grasslands and Shrub Lands

The grasslands and shrub lands (sometimes referred to as sandveld or Kalahari thornveld) of the southern Kalahari cover a major portion of Botswana (excluding the Okavango Delta, Chobe and Gabarone areas) and extend into parts of Namibia and South Africa. Derived from the Tswana word “Kgalagadi”, meaning “the great thirst”, the Kalahari is a stark landscape dominated by sand dunes and plains, pans and dry fossil riverbeds. There is a lack of surface water, as sand transports water to deep aquifers. Yet, fire is a significant part of this landscape, and under favorable conditions, it can burn large tracts of land.

The climate of the Kalahari is semi-arid, with a summer rainfall regime (October to March). The southwest-portion of the Kalahari receives an average of 200 mm rainfall, while the north and east receive an average of 500 mm per year. The region is subject to great variability in precipitation, which, in turn, influences the occurrence and extent of fire. This variability is both spatial and temporal. Most rains occur as a result of thunderstorms, which derive their moisture from the Indian Ocean. The flow of this moisture is restricted by the Drakensberg mountains of South Africa, and only the most intense flows are likely to reach the Kalahari. In some years, supplemental

moisture can reach the Kalahari from the Congo River basin, increasing rainfall amounts. In a given year, one area may receive more than three times the rainfall in another area (Mills & Haagner, 1989) and rainfall in the same area may vary from 57 mm to 660 mm between years (Mills & Haagner, 1989).

The vegetation of this area is dominated by grasses, primarily annuals. Grasses such as Kalahari coach (*Stipagrostis amabilis*), Lehmann's lovegrass (*Eragrostis ehmanniana*), Kalahari grass (*Schmidtia kalahariensis*) and Giant stick grass (*Aristida meridionalis*) cover the sand plains and dunes. Trees and shrubs, including deep-rooted *Acacia* spp., are generally limited to riverbeds and pan edges in the southern Kalahari, while areas of open woodland are present to the north. Typical species include the Grey Camelthorn (*Acacia heamatoxylon*) and Camelthorn (*Acacia erioloba*). Sheppard's tree (*Boscia albitrunca*), Black thorn (*Acacia mellifera*), and False umbrella thorn (*Acacia luederitzii*) exist on dunes in widely scattered locations.

Information on the fire ecology of the Kalahari is very limited. However, comparisons to other semi-arid grassland communities can assist in the understanding of fire occurrence in the Kalahari. In these grasslands, fire occurrence is dependent on the fuel arrangement, volume and condition, which are all governed to a great extent by rainfall. During dry years, production of grasses is minimal and fire is restricted by low fuel continuity and volume. During wet years, grasses may form dense fuel beds which, when cured during the dry winter period and by frost, are conducive to the spread and intensity of large fires.

In the Kalahari, evidence suggests a strong relationship between wet years and the occurrence of fire. When precipitation is plentiful, Kalahari grass (*Schmidtia kalahariensis*) and other grasses can form dense stands (Mills & Haagner, 1989). This can dramatically increase the fuel load. In 1974 and 1976, the Kalahari received substantial rains, which resulted in significant grass production. In the following drier years, fires started by lightning burned over large tracts of the Kalahari, damaging and killing mature Camelthorn trees (*Acacia erioloba*) and affecting associated plant communities (Mills & Haagner, 1989). Although there is scant information on fire return intervals in the Kalahari, it appears that these large fire episodes occur every 10–15 years on average, corresponding with wet cycles.

It appears that lightning accounts for a larger percentage of fires than other areas in Africa, where human activity is the cause of most fires. This is probably due to low population densities in the Kalahari.

Lacking adequate data, one must presume there are specific fire plant adaptations, given the long history of fire in the region. These fires have almost certainly served to sustain the ecosystem, but human presence and accompanying activities such as ranching, farming, mining and tourism, have increased rapidly (Moyo et al., 1993) and will impact the fire ecology in three ways: The first will be a change in vegetation and lower fuel loads, where ranching and farming occurs. This could affect the extent of large fires with an effect on fire ecology of the area. Next, the risk of accidental fire and the traditional use of fire as a tool for vegetation manipulation will certainly

increase the number of fires above the historical level. Finally, fire damage to villages, farms and industrial operations will increase as human activity in the area increases. The end result could be significant change in the area's ecology (outside protected areas). The role of fire in this future scenario is uncertain.

2.4 WOODLAND AND WOODLAND MOSAICS

Woodland can be defined as “an open stand of trees, at least 8 m tall, with a canopy cover of 40% or more” (White, 1983). Crowns of adjacent trees are often in contact, but are not densely interlocking. Most African woodlands are deciduous or semi-deciduous, but nearly all types contain a few evergreen species. The field layer is usually dominated by herbaceous tussock grasses, which are usually perennial. Annual grasses are predominant in certain transitional types, especially under the influence of heavy grazing. In most types there is an incomplete understorey of small trees, or large bushes of variable density. Occasionally, stands of woodland have a closed canopy with a poorly developed grass layer, and are referred to as “closed woodland”. A wide range of vegetation types have been described by White (1983):

- **Zambezian dry evergreen forest** (Guineo-Congolian rainforest – Zambezian Woodland transition)
- **Zambezian dry deciduous forest** (most extensive deciduous forests are *Baikiaea* forests, on Kalahari sand)
- **Woodland** (most widespread and characteristic vegetation of the Zambezian Region)

Three distinct woodland types have been identified, plus two others:

- **Miombo Woodland:** It is absent from southern and extreme western fringes of the region, and from large parts of the Kalahari sands. Floristically and physiognomically it is very different from other woodland types, nearly always dominated by *Brachystegia*, either alone or with *Julbernardia* or *Isoberlinia*. Most miombo species are semi-light-demanding and show some degree of fire resistance, but dominants cannot survive repeated fires. A distinction is made between **Wetter Miombo** and **Drier Miombo**.
- **Mopane Woodland** and **Scrub Woodland** are widespread in the drier half of the region, and in main river valleys. Mopane has a shallow root system with a dense concentration of fine roots in the topsoil. Grass is sparse or absent. Mopane trees can tolerate repeated fires and sprout vegetatively after fire.
- **Undifferentiated (north and south) Zambezian Woodland.** It is floristically rich, more easily defined by absence of miombo and mopane dominants.
- **Kalahari Woodland** is considered as modified forest (by fire and cultivation) on the Kalahari sands of the upper Zambezi basin (deciduous *Baikiaea plurijuga* forest in the south).
- **“Chipya” Woodland** grows on suitable soils on the Central Africa Plateau in parts of Zambia, Zaire (Shaba) and Malawi, where rainfall exceeds 1000 mm per year,

and is found on alluvial soils of lake basins and their associated river systems, owing its existence to cultivation and fire.

- **Itigi deciduous thicket** is the only extensively occurring one of several types of thickets, which is found scattered throughout the Zambezian Region.

2.5 LOWLAND, MONTANE AND COASTAL FORESTS

“Forest” is a continuous stand of trees, at least 10 m tall, and with their crowns interlocking (White, 1983). In South Africa, forest as a vegetation unit includes scrubforest, *i.e.* stands of interlocking tree crowns with a height of 3 to 10 m, if the understorey is open (Geldenhuys et al., 1988). White (1983) gave a general description of forests. Woody plants, particularly trees, contribute most to the physiognomy and biomass, and often also to species richness. A shrub layer is normally present. In tropical and subtropical forests, grasses (if present) are comparatively localised and inconspicuous. Lianas and vines are often well represented. Epiphytes, including ferns, orchids and mosses, are characteristic of the moister tropical and subtropical forests, but vascular epiphytes are almost absent from the more temperate (southern latitudinal) forests. Nearly all the forests in Africa are evergreen or semi-evergreen, although semi-deciduous forests occur locally. Some canopy tree species of semi-evergreen forest are briefly deciduous, but not necessarily at the same time, and most understorey woody plants are evergreen.

The term “rain forest” or “rainforest” is often used to describe the mixed evergreen forests.

Although it seems appropriate to use the terms only for the Guineo-Congolian forests on well-drained soils, other mixed evergreen forests – which in structure are almost indistinguishable and floristically closely related to Guineo-Congolian rainforest – occur outside the Guineo-Congolian Region, often in montane areas. In this book we will use the term “forest” for these mixed evergreen forests. It excludes the dry evergreen forest and dry deciduous forest, which is localised in the Zambezian and Sudanian Regions with a dry season which lasts several months.

The main forest types have been classified by White (1983). Wetter and drier types of Guineo-Congolian lowland rain forest and mosaics of the two types, with swamp forest, with secondary grassland and with woodland; forests of the East African coastal mosaic; Undifferentiated Afromontane forests; and Transitional forest between lowland and montane forests in East Africa.

2.5.1 Guineo-Congolian Lowland Forests

This region stretches as a broad band, north and south of the equator, from the Atlantic Ocean coastline eastwards through the Congo Basin to the western slopes of the Kivu Ridge, where the lowland forests give way to the Afromontane forests. Nearly everywhere the altitude is less than 1000 m, and the Congo Basin has an average altitude of 400 m. Compared with rainforest areas in other continents, most of the Guineo-Congolian Region is relatively dry, with 1600 to 2000 mm rainfall per year and a less even distribution throughout the year. Further away from the equator, and towards the Atlantic coast at equatorial latitudes, the length and severity of

the dry season increases. In West Africa, the *harmattan* (a north-easterly desiccating wind from the Sahara) at times reaches the forest zone. Relative humidity in Ghana, for example, falls to 53%. Further east, a similar wind blows from the Ethiopian highlands and the Nile Valley and influences the rainforest climate in that area (White, 1983).

The greater part of the Guineo-Congolian Region was formerly covered with rainforest on well-drained sites and swamp forest on hydromorphic soils. Today, little undisturbed forest remains, and secondary grassland and various stages of forest regrowth are extensive.

The gradual and continuous variation in floristic composition, physiognomy and phenology, and the poor correlation of the distribution of many species with obvious environmental factors, make sub-division of Guineo-Congolian forests difficult. Four main types have been distinguished (White, 1983):

- **Hygrophilous coastal evergreen forest** occurs in three blocks of varying width along the Atlantic coast of Africa from Sierra Leone to western Gabon, and is generally very rich in legume tree species, which often form almost pure stands with abundant regeneration.
- **Mixed moist semi-evergreen forest** form the most extensive area of Guineo-Congolian forests, except in the wettest and driest extremes, particularly in the Congo Basin.
- **Drier peripheral semi-evergreen forest** occurs in two bands running transversely across Africa to the north and south of the main block of mixed moist semi-evergreen

forest. Where this type of forest is in contact with savanna, it is susceptible to damage by ground fires, which burn the litter and kill shrubs and young trees. In Ghana such fires – at intervals of up to 15 years – give rise to a distinct “fire-zone” variant (Hall & Swaine, 1976, in White, [1983]). The forest can maintain itself if the fires are sufficiently infrequent.

- **Single-dominant moist evergreen and semi-evergreen forest** occur as small islands of a few hectares in extent, in a broad band surrounding the Congo Basin.

Other forests in the Guineo-Congolian Region include:

- **Short forest and scrub forest** occur on rocky hills and other upland areas, but are not Afromontane forest, and are floristically poorer, shorter and with simpler structure than the typical lowland forests.
- **Swamp forest and Riparian forest** occur throughout the region wherever conditions are suitable. They appear similar to the rainforests, but the main canopy is irregular and relatively open.
- **Transition woodland, with secondary grasslands and wooded grassland** replace both lowland rainforests and transition forest due to fire and cultivation. When fire is excluded or its intensity reduced (as had been studied in detail at Olokemeji in Nigeria), such grassland reverts to forest if propagules of forest species are available (Charter & Keay, 1960; Clayton, 1958, in White [1983]). Succession to forest was found to be relatively

slow, and after 31 years of fire protection, the canopy was only 8 to 11 m tall.

2.5.2 Montane Forests

The Afromontane forests occur in an archipelago-like pattern. They extend from mountains in Sierra Leone in west Africa to the Ahl Mescat Mountains in Somalia in the east, and from the Red Sea Hills in Sudan in the north, through Tanzania, Malawi, Mozambique, Zimbabwe and finally along the Drakensberg Escarpment and other mountains, to the Cape Peninsula mountains in South Africa in the south. In the tropics, most Afromontane communities occur above 2000 m, but further south, latitude compensates for altitude and communities descend progressively further, and along the South African southern coastline they occur to almost sea level. They are generally small, fragmented patches, very often smaller than 100 ha. The mean annual rainfall is 800 mm to more than 2500 mm, but less in drier types, transitional to lowland vegetation. On most mountains the lowermost vegetation is forest, beneath which one would expect to find a transition zone connecting the Afromontane and lowland phytochoria. Nearly everywhere, however, the vegetation of this transition zone has been destroyed by fire and cultivation.

In southern Africa, primarily South Africa, Afromontane forests have a dispersed distribution in small patches in sheltered areas of mountain ranges, ranging from sea level to 1500 m where the rainfall is above 700 mm per year. Typical trees include *Podocarpus* spp., *Olea europea*, *Trichocladus ellipticus*, *Rhus chiredensis*, *Curtisia dentata*, *Calodendrum capense*, *Ocotea bullata* and *Kiggelaria*

africana. Different types of Afromontane forest, have been described by White (1983):

- **Afromontane rain forest**, mostly between 1200 m and 2500 m, with rainfall between 1250 mm and 2500 mm per year, i.e. on the wetter slopes of the higher mountain massifs from southern Ethiopia to Malawi.
- **Undifferentiated Afromontane forest** is usually shorter than Afromontane rain forest, which it replaces at higher altitudes on the wetter slopes and at comparable altitudes on drier slopes, and also at lower altitudes.
- **Single-dominant Afromontane forest** occur with three types:
 - *Juniperus procera* forest, scattered distribution from Red Sea Hills in Sudan south to the Nyika Plateau (Malawi). Its presence is largely dependent on fire (natural or man-made).
 - *Widdringtonia* forests extend from southern South Africa (Cedarberg Mountains) to Mount Mulanje in Malawi. These forests are very susceptible to fire. The behaviour of *Widdringtonia* in relation to fire is similar to that of *Juniperus procera*.
 - *Hagenia abyssinica* forest – on most of higher mountains between Ethiopia and the Nyika Plateau in Malawi. The species is a light-demander, which can withstand at least some burning, although mortality occurs if exposed to repeated high intensity fires.

Although Afromontane forests vary in species composition, they have much in common when

the role of fire and its effects are considered. Generally, non-degraded Afromontane forests do not readily burn due to their structure, separation from the litter layer and their higher fuel moistures (Van Wilgen et al., 1990). Crown fires are extremely rare in the Afromontane forests (Kruger & Bigalke, 1984). However, fire does play a significant role in controlling the extent of Afromontane forests. Often areas of fire-prone vegetation exist adjacent to Afromontane forests, where frequent fires can eat away at the forest margin. Many of the forest tree species have not adapted to fire and are sensitive to its impact, except for a few deep-rooted trees, most of the overstorey trees are killed by ground fires (Geldenhuys, 1977). For example, fires observed in the moist Afromontane forests of Kenya and Ethiopia during the drought of 2000 (Goldammer, 2000), exhibited low-fire behaviour, often creeping along the litter layer, occasionally igniting vines and mosses, which carried the fire into the forests' crowns. These slow-moving surface fires often followed pathways into the root system of older trees, where they burnt to a depth of one to two metres, creating very high soil temperatures. Even the thickest bark would not protect a tree from this type of fire. It is likely that tree mortality was high in these areas.

Afromontane forests can also expand their area if the site conditions are favourable and fire frequency is low. For example, in South Africa, Afromontane forests are usually restricted to areas protected from frequent fires, such as scree slopes and moist valleys. Safeguarded from fire for over 50 years by firebreaks and its southern exposure, the Orange Kloof area of Table Mountain

has been colonised by forest species that have replaced the fire-adapting fynbos (Manders et al., 1992). This example is an exception, as most Afromontane forests are currently being reduced in size by human encroachment and fire.

Humans in and around the Afromontane forest have used fire to manipulate the landscape and to extract resources for thousands of years (Granger, 1984). In the northern extent of Afromontane forest range, grassy glades have become a common feature due directly to burning for pasture improvement. In order to clear land for cultivation or grazing, those intending to settle in the forest set the vegetation on fire and fell trees. Fires from honey hunters often dot Afromontane forests. During the dry season, these fires can creep through the forest, killing individual large trees, which in turn create openings in the canopy. Charcoal burners, using traditional kilns, also affect the forest as their fires often spread to surrounding forested areas. Often, fires set at lower elevations for agricultural purposes escape, are burning uphill into the Afromontane forest margin, and during prolonged droughts, penetrating the central forest. The net effect of these fires and tree felling are the opening up of the forest canopy, changing the delicate micro-climate, and allowing fire-prone vegetation, such as grasses and flammable shrubs, to dominate (Phillips, 1931; 1963). These changes are leading to a cycle of more frequent fires and a reduction in size of most Afromontane forest. It is clear that increasing human populations in and adjacent to Afromontane forests are directly and indirectly leading to eradication of much forest (Granger, 1984).

2.5.3 Coastal Forests

The coastal forests form part of the Zanzibar-Inhambane regional mosaic and the Tongaland-Pondoland regional mosaic. The Zanzibar-Inhambane forests occur in a coastal belt of 50 to 200 km wide, from southern Somalia to the mouth of the Limpopo River in southern Mozambique. Most of the land lies below 200 m. Rainfall is mostly between 800 and 1200 mm per year, with a well-defined dry season. Forest is the most widespread climax vegetation, but has been largely replaced by secondary wooded grassland and cultivation. Three types of forest have been identified (White, 1983):

- Zanzibar-Inhambane lowland rain forest
- Transitional rain forest
- Zanzibar-Inhambane undifferentiated forest

The Tongaland-Pondoland forests extend along the coast south of the Zanzibar-Inhambane Region, from the Limpopo River to Port Elizabeth. Three types have been identified (White, 1983):

- Tongaland-Pondoland undifferentiated forest
- Tongaland-Pondoland evergreen and semi-evergreen bushland and thicket
- Kalahari thornveld and the transition to Zambezi broadleaf woodland

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3

FIRE BEHAVIOUR

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3.1 FIRE BEHAVIOUR: INTRODUCTION

Fire behaviour is the general term used to refer to the release of heat energy during combustion as described by the rate of spread of the fire front, fire intensity, flame characteristics and other related phenomena such as crowning, spotting, fire whirlwinds and fire storms.

The effect of fire on natural ecosystems involves the response of living organisms to the release of heat energy through the combustion of plant material. The manner in which, and the factors that influence, the release of heat energy, involves the study of fire behaviour. In Africa there is a serious deficiency of knowledge concerning the behaviour of fires, and this is particularly applicable to the savanna and grassland areas of the continent. Virtually no attempt has been made to quantify the dynamics of the release of heat energy during a fire and the subsequent response of plants to it. The determination of such relation-

ships helps explain many of the apparently inexplicable effects of fire, which are often cited in the literature. Research on the effects of fire has been conducted throughout the grassland and savanna areas of Africa, particularly in southern Africa, since the early period of the 20th century (West, 1965). An interesting feature about these early investigations and subsequent research up until 1971, was that it focused on the effects of season and frequency of burning on the forage production potential of the grass sward and the ratio of bush to grass in savanna areas (West, 1965; Rose-Innes, 1971; Scott, 1971; Gill, 1981). However, in 1971, a conference was convened in the United States of America by the Tall Timbers Research Station at Tallahassee, Florida, on the theme of "Fire in Africa". This congress was attended by fire ecologists from throughout Africa. The major benefit that accrued from this conference was the realisation that in Africa the study of fire

behaviour and its effects on the ecosystem, as described by type and intensity of fire, had been largely ignored in all the fire research that had been conducted up until that time. As a consequence of this, a research programme was initiated in South Africa, which was later extended to East Africa. The purpose of this programme was to characterise the behaviour of fires burning in savanna and grassland vegetation, and to determine the effect of fire type and intensity on the vegetation.

Knowledge of fire behaviour is extremely important for rangeland and forest fire managers to enable them to apply prescribed burning to achieve the desired effect, and to ensure that fire suppression tactics are applied successfully. It will assist them in all fire-related management, control decision-making and make them more efficient in their role as fire managers. Fire managers, experienced in understanding fire behaviour, can also train fire fighters more effectively in the application of prescribed burning and the suppression of wildfires.

There is a serious lack of quantitative data on the effect of various factors on the behaviour of fires in Africa. Conversely, in the USA and Australia, the study of fire behaviour is more advanced, and very sophisticated mathematical models have been developed to predict the behaviour of fires. However, Luke and McArthur (1978) in Australia believe that for practical field use the fire models that have been developed by Rothermel (1972) and others in the USA are difficult to apply in the field. They prefer, instead, simpler models based on general fuel characteristics such as particle size, distribution, and moisture content together

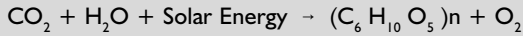
with the slope, relative humidity, air temperature and wind speed.

A similar approach to Australia has been generally adopted in the savanna and grassland areas of South Africa, where the effect of different variables on fire intensity was investigated in the Eastern Cape Province and in the Kruger National Park (Trollope, 1978; Trollope, 1983; Trollope & Potgieter, 1985). Attention was focused on fire intensity because it is easy to measure, and research has shown that it is significantly correlated with other fire behaviour parameters, such as rate of spread, flame height and temperatures recorded at different heights above the ground during burning. The factors influencing the behaviour of fires will be discussed in terms of those variables that should be considered when applying controlled burns. A review of the literature reveals that these can be listed as fuel, air temperature, relative humidity, wind speed and slope (Brown & Davis, 1973; Luke & McArthur, 1978; Cheney, 1981; Leigh & Noble, 1981; Shea et al., 1981; Wright & Bailey, 1982).

3.2 PRINCIPLES OF COMBUSTION

3.2.1 Introduction

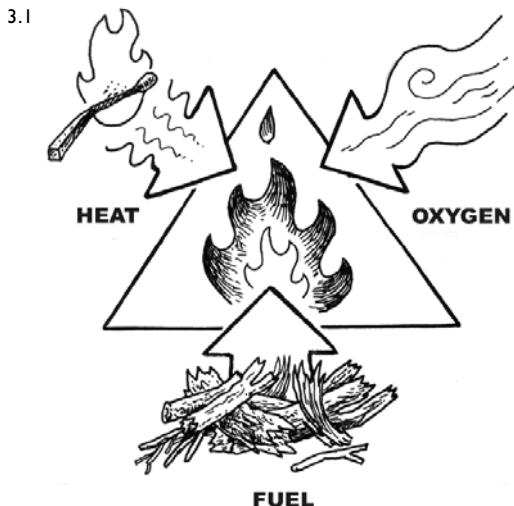
The study of fire behaviour necessitates a basic understanding of the phenomenon of combustion. This, according to Brown and Davis (1973), is an oxidation process comprising a chain reaction where the heat energy released during a fire originates from solar energy via the process of photosynthesis. Combustion is similar to photosynthesis in reverse and is clearly illustrated in the following two general formulae:

Photosynthesis**Combustion**

The kindling temperature in the combustion formula merely has a catalytic role of initiating and maintaining the combustion process.

3.2.2 Fire Triangle

To illustrate the principles of fire combustion, use is made of the FIRE TRIANGLE, where each of the three sides represent the three essential elements necessary for combustion, namely: FUEL, HEAT and OXYGEN.



All three elements are necessary for fire, and removing one, will make it possible to extinguish a fire. The role the three elements play in fire, can be illustrated as follows (Heikkilä et al., 1993):

- **Oxygen** – 21 % of the air is oxygen. A reduction in oxygen to 15% extinguishes a fire. This can be achieved by either smothering or covering the fire using sand, fire swatters, sacks and branches.
- **Fuel** – Wildfires are primarily controlled by focussing on the fuel component side of the fire triangle. This is done by confining the fire to a definite amount of fuel by means of a fire line and barriers, if available. By keeping the flames within the fire line, the fire is controlled. The fire line is usually constructed by removing the surface fuel with tools or equipment so that the mineral soil is exposed, or by wetting down the width of the fire line with water.
- **Heat** – In order to ignite a fire, fuel must be brought to its ignition temperature. If the heat drops below the ignition temperature, the fire goes out. Water is the most effective agent for this reduction of heat. Smothering the fire

Figure 3.1. The Fire Triangle.

with sand also helps to reduce the heat, thereby extinguishing the flames.

3.2.3 Fire Ignition

An important source of fire ignition is human activity. Arson, accidental or prescribed burns, can all give rise to the development of wildfires from a wide variety of heat sources, such as glowing cigarette butts, matches and sparks from power lines. Lighting has been the main non-human means of ignition in many African regions, but earthquakes can start fires by dislodging rocks from mountain sides (De Ronde, pers. obs., Wolseley District, South Africa, 1969), and landslides or volcanic activity can also be sources of ignition. In most cases, the human factor, however, becomes more and more important as population density increases, and Africa is a prime example of this phenomenon.

The ignition temperature can be defined as “the temperature of a substance at which it will ignite and continue to burn without any additional heat from another source” (Heikkilä et al., 1993). The moisture content of the fuel particles will determine the ease of ignition in dead (cured) grass, e.g. a sustained flame is required for ignition at a moisture content above 15%. Ignition will become progressively easier as the moisture content of dead fuel decreases, and below a moisture content of 6%, very small embers or hot particles are capable of igniting grassy fuels (Cheney & Sullivan, 1997).

The size of the fuel in relation to the heat applied is also important in determining whether or not the fuel will reach its ignition temperature, and more heat units will have to be applied

to larger size fuel than to a smaller size fuel in order to reach ignition temperature (Heikkilä et al., 1993).

3.2.4 Combustion and Heat Transfer

In rangeland and forest fires, all fuels proceed through the following three burning phases:

Phase 1: Preheating – Fuels ahead of the flame front are raised to their ignition point and involve the driving off of moisture and the generation of flammable hydrocarbon gases.

Phase 2: Gaseous phase – The pre-heated fuel breaks down into gases and charcoal and flaming combustion occurs.

Phase 3: Combustion – The gases burn off and the residual charcoal is consumed by glowing combustion.
(Davis, 1959).

The amount of heat energy released during the flaming and glowing phases of combustion varies with different fuel types. Heavy fuels with low flames generally release a large proportion of their heat energy, albeit at a slower rate, via glowing combustion (Brown & Davis, 1973). Conversely, light fuels (such as grass) release the majority of the heat energy during the flaming combustion.

The three phases of combustion overlap and occur simultaneously during a fire. Nevertheless, they are easily recognised, and comprise firstly the zone in which the leaves and other fine fuels curl and are scorched by the preheating of the oncoming flames. This is followed by the flaming zone of burning gases, which is followed, in turn,

by the third but less conspicuous zone of burning charcoal (Brown & Davis, 1973). The maintenance of the chain reaction of combustion during a fire involves the transfer of heat energy to the burning and potential plant fuel via the processes of conduction, convection, radiation and the movement of hot or burning plant material through spotting (Steward, 1974).

Besides spotting, the transfer of heat in a moving fire front is mainly due to convection and radiation. Convection currents are primarily responsible for the preheating of the higher shrub layers and tree crowns, while the radiation from the flames accounts for most of the preheating of the fuel ahead of the fire front (Luke & McArthur, 1978).

Heat transfer can take place in the form of:

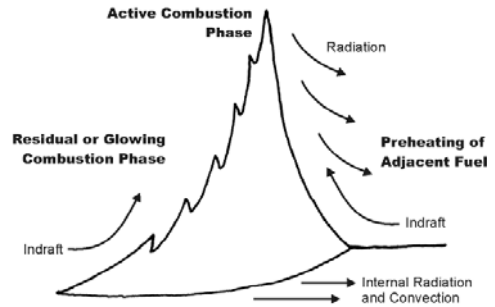
Radiation – Transfer of heat through space, in any direction, at the speed of light.

Convection – Transfer of heat by the movement of hot air and other heated gases.

Conduction – Transfer of heat within a fuel unit, or from one fuel particle to another, by direct contact. This fuel heating process has little relation to vegetation fires.

Mass Transport – Particularly important in wildfires, when e.g. spotting occurs.

The role of radiation and convection in the spread and maintenance of a fire is illustrated in Figure 3.2 below:



3.3 FUEL DYNAMICS

3.3.1 Fuel Sizes, Types and Classification

Fuels can be composed of any woody or other plant material – either living or dead – that will ignite or burn. The two main fuel sizes are:

Fine Fuels – Grass, small branches, pine needles and leaves with a diameter of up to 6 mm. They dry very fast and need little heat to ignite. If well aerated, they will burn rapidly, but if they are compacted, they can burn very slowly.

Coarse Fuels – Thicker branches, logs and stumps. These fuels dry slowly and require more heat to ignite, but once burning, will continue to burn (or glow) for extended periods of time.

Well-aerated fuels – such as African grasslands – are known for the fast rate of the spread of the fire front, particularly when curing is complete. However, grassfires have a relatively lower fire intensity per unit area (heat per unit area) than, for instance, forest (or plantation) fuels with a

Figure 3.2. Flame profile of a fire on a horizontal surface with no wind, indicating the region of pre-heating, flaming combustion and glowing combustion (Whelan, 1997).

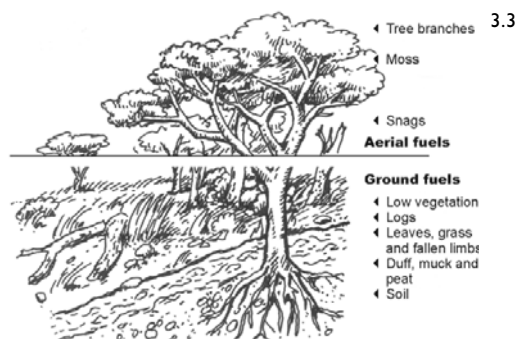
compacted forest floor consisting of needles or leaves. The latter dry slowly (because they are less aerated) and produce a slower fire rate of spread – though normally with a higher fire intensity per unit area. The vertical distribution of fuel (also called surface-to-volume ratio) is therefore a very important factor determining potential fire behaviour, together with fuel volume. Fuel in grasslands, savannas and forests can be classified in three main groups, namely: ground fuels, surface fuels and aerial fuels.

Ground fuels include all combustible material below the loose surface litter and comprise decomposed plant material. These fuels support glowing combustion in the form of ground fires and, although very difficult to ignite, are very persistent once ignited (Brown & Davies, 1973).

Surface fuels occur as standing grass swards, shrublet communities, seedlings and forbs. They also include loose surface litter like fallen leaves, twigs and bark. All these materials are fine fuels and can support intense surface fires in direct proportion to the quantity of fuel per unit area (Brown & Davies, 1973).

Aerial fuels include all combustible material, live or dead, located in the understorey and upper canopy of tree and shrub communities. The main aerial fuel types are mosses, lichens, epiphytes, branches and foliage of trees and shrubs (Brown & Davies, 1973). This fuel type supports crown fires.

Where continuous crown canopy fuels occur (such as in industrial, even-aged, plantations), crown



fires can develop, provided sufficient surface fuel is available to increase the fire intensities of surface fires to initiate crown fires, with sufficient wind to maintain this process.

Within certain fuel types, fuels can be classified according to their ignition potential and predicted fire behaviour, and the two most commonly used classifications in sub-Saharan Africa are:

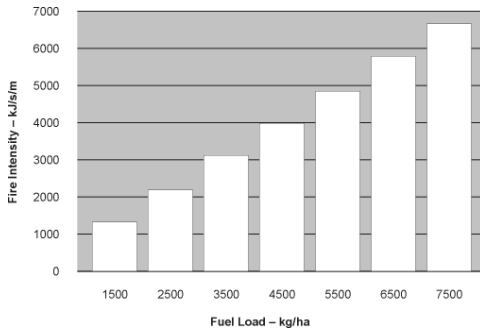
- **Fuel classification in Natural Grassland** – The percentage curing of grassland is used to estimate fuel availability and to determine when curing is complete.
- **Fuel classification in Industrial Timber Plantations** – Five main classes have been identified, which are classified according to the degree of aeration, fuel depth and other fuel characteristics, to arrive at the degree of suitability for applying prescribed burns (De Ronde, 1980).

3.3.2 Fuel Depth, Loading and Compaction

The ultimate determinant of fire intensity is the amount of energy stored in the fuel. Fuel load, or total mass of fuel per unit area, is a readily

Figure 3.3. Illustration of vertical fuel distribution.

3.4



measured indicator of this component. The dry mass of fuel should be considered as the amount of potential fuel, because few fires actually achieve complete combustion of the above-ground biomass, of any size classes of fuel. A more realistic estimate of the fuel load is the available fuel, which takes into account the size and arrangements of fuels (McArthur & Cheney, 1972, in Whelan [1997]).

Fuel load is regarded as one of the most important factors influencing fire behaviour because the total amount of heat energy available for release during a fire is related to the quantity of fuel (Luke & McArthur, 1978). Assuming a constant heat yield, the intensity of a fire is directly proportional to the amount of fuel available for combustion at any given rate of spread of the fire front (Brown & Davis, 1973). The highly significant positive effect fuel load has on fire intensity was investigated in the Eastern Cape Province and Kruger National Park in South Africa, and is illustrated in Figure 3.4.

The most practical and efficient method for estimating grass fuel loads is with the disc pasture meter developed by Bransby and Tainton (1977).

Calibrations for the general use of the disc pasture meter in the savanna areas of the Eastern Cape Province and north-eastern savanna areas of Mpumalanga and the Northern Province in South Africa have been developed by Trollope (1983) and Trollope and Potgieter (1985). The respective regression equations are:

Eastern Cape Province

$$y = 340 + 388.3x$$

Mpumalanga & Northern Province

$$y = -3019 + 2260 \sqrt{x}$$

where: y = mean fuel load – kg/ha
 x = mean disc height – cm

The depth of fuel (i.e. its vertical distribution) is also important, as this will determine the drying rate of fuel, fire intensity and rate of spread (if correlated with variations in fuel compactness). A compact fuel layer (such as the forest floor of a mature Pine stand) will provide a slow rate of spread with an even flame distribution and few flare-ups, while a well-aerated fuel (such as grassland) with a high vertical distribution per unit area will produce an irregular flame pattern with common flare-ups and with a fast rate of fire spread, but with a relatively low fire intensity per unit area and a normally high fire line intensity. The fuel height (depth) or fuel volume alone does not regulate a fire front rate of spread, but

Figure 3.4. Effect of fuel load on fire intensity recorded in South Africa (Trollope & Tainton, 1986; Trollope & Potgieter, 1985).

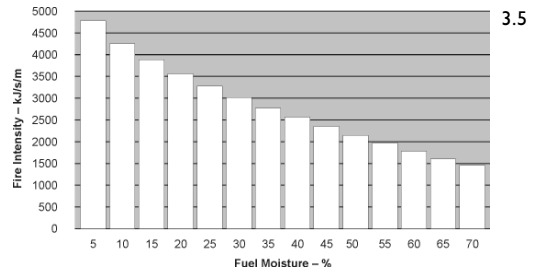
the higher the fuel height is, the higher the flames will be. This vertical distribution of the fuel (the volume-to-area ratio) can have a significant effect on the rate of spread of the fire front.

Fuel compaction refers to the placement of individual pieces of fuel in relation to one another. Combustion is most favoured when fuel is sufficiently loosely packed to enable adequate quantities of oxygen to reach the flame zone, but dense enough for efficient heat transfer to occur. Fuel spacing is especially critical in heavy fuels, but adequate ventilation generally occurs in the majority of fuel types (Luke & McArthur, 1978).

3.3.3 Fuel Moisture

The rate of combustion of cold, moist fuels, is slower than that for hot, dry fuels. Fuel moisture is obtained from the atmosphere, precipitation and the ground. Local climate will determine the relative humidity of the air, and when the air humidity is high the moisture content of the fuel will be high with low humidity, providing low moisture content. However, sudden increases or decreases in air humidity – such as when a cold front approaches or when bergwind conditions are suddenly experienced – will on their own not have an immediate effect on fuel moisture content, particularly on the moisture content of coarser, heavy fuels. Air humidity effect is significantly influenced by air temperature, wind, precipitation, time of the day, topography and other factors, which in turn all have a combined significant effect on fuel moisture content.

Fuel moisture is normally expressed on a dry



matter basis and is a critical factor in determining the intensity of a fire because it affects the ease of ignition, the quantity of fuel consumed and the combustion rate of the different types of fuel. The most important influence of fuel moisture on fire behaviour is the smothering effect of the water vapour released from the burning fuel. It reduces the amount of oxygen in the immediate proximity of the burning plant material, thus decreasing the rate of combustion (Brown & Davis, 1973).

Luke and McArthur (1978) distinguish between the moisture content of living plant tissue and cured plant material. The former varies gradually in response to seasonal and climatic changes, whereas cured plant material is hygroscopic and the moisture content is affected on an hourly and daily basis, mainly by absorption and desorption in response to changes in the relative humidity of the adjacent atmosphere.

The negative effect of fuel moisture on fire intensity was investigated in the Eastern Cape Province and in the Kruger National Park in South Africa, and is illustrated in Figure 3.5.

Figure 3.5. Effect of fuel moisture on fire intensity recorded in South Africa (Trollope & Tainton, 1986; Trollope & Potgieter, 1985).

3.4 FIRE WEATHER

3.4.1 Wind

Wind is the most dynamic variable influencing fire behaviour. It provides more oxygen to the fire front and affects the rate at which fuels dry ahead of the fire front. This causes pre-heating in front of the fire by means of radiation from the flames, thereby preparing it for ignition and promoting the spread of the fire front.

An increase in wind speed will increase the drying rate of fuel, while the wind direction will determine in what direction the back fires and head fires will spread. The stronger the wind, the faster will be the rate of spread of a head fire burning with the wind. The stability of the air will also influence both wind speed and direction, and unstable air – as experienced in rough terrain or with an oncoming frontal system – can also change the direction and variability of the wind speed.

The combustion rate of a fire is positively influenced by the rate of oxygen supply to the fire (Brown & Davis, 1973; Cheney, 1981), hence the effect of wind speed on fire behaviour. Wind also causes the angle of the flames to become more acute. With increased wind velocities, the flames are forced into the unburned material ahead of the fire front, resulting in more efficient pre-heating of the fuel and greater rates of spread in surface head fires (Luke & McArthur, 1978; Cheney, 1981). Beaufait (1965) found that wind speeds ranging from zero to 3.6 m/s increased the rate of spread of surface head fires exponentially, but had no effect on the rate of spread of back fires. Apparently this effect on backing

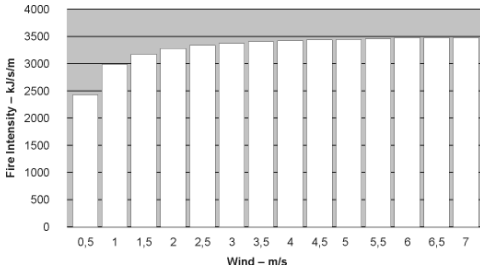
fires is a widely observed phenomenon (Gill, 1980). Beaufait (1965) suggested that even though flames are blown away from the fuel immediately adjacent to the fire front during backing fires, flame propagation results from preheating and ignition mechanisms occurring beneath the surface of the fuel.

Brown and Davis (1973) and Luke and McArthur (1978) stated that increased wind speeds cause greater rates of spread, and therefore more intense fires. However, flame height does not necessarily increase with increased wind speed because these cause the flames to assume a more acute angle and this may prevent the ignition of aerial fuels. This partly explains why crown fires do not always occur during high winds. Luke and McArthur (1978) stated, however, that once the wind velocity exceeds 50 km/h (13.9 m/s) the rate of spread of fires in grassland tends to decrease. This is probably because, as wind speed and rate of spread increase, the amount of fuel consumed in the flaming zone of the fire tends to decrease and the flames are blown out. This phenomenon appears to occur only when the fuel load of grass is low (Brown & Davis, 1973; Cheney 1981).

Research in the Eastern Cape Province and the Kruger National Park in South Africa shows that, under atmospheric conditions suitable for controlled burning, wind plays a significant but non-dominant role affecting fire intensity. This is illustrated in Figure 3.6.

Wind speed is in most cases at its maximum between 12:00 and 15:00, but this can vary with frontal activities and terrain. Bergwind conditions can reach maximum wind speed at any time of the day or during the night. Bergwinds are gusty,

3.6



hot, desiccating, north-westerly to north-easterly and blow from the arid interior across the coastal mountains onto the coast. They are associated with low-pressure cells moving from west to east along the coast (Tyson, 1964). A bergwind is similar in effect to the *Föhn* of the European Alps, i.e. a warm dry wind descending in the lee of a mountain range (Brinkmann, 1971). The greatest forest fire on record in the Southern Cape, South Africa, occurred during a bergwind in February 1869, and burned along the southern coastal areas from Swellendam to Uitenhage (South Africa), a distance of > 500 km (Phillips, 1931; 1963; Edwards, 1984). The fire occurred after a hot dry period of six weeks that reached a maximum on the day of the fire with a scorching hot dry northerly bergwind and high temperatures that attained 34°C at 08:00 and 45°C at 14:00 (Edwards, 1984). Similar devastating fires occurred in South Africa at Bergplaas (1962) and Witfontein (1964), both near George in the Southern Cape, at Longmore (1984) near Port Elizabeth, and again in several parts of the same area during 1996 and 1998. These fires burned down large areas of pine plantations and fynbos, but rarely entered the adjacent indigenous forest.

The prevailing wind conditions in the landscape during different seasons have a particular impact on the fire regime. For example, hot, dry, gusty, *Föhn*-like winds occur in different parts of Africa (*Harmattan* in West Africa, bergwinds in southern Africa). The bergwinds blow particularly during the winter months (the dry periods in summer rainfall areas) and can cause devastating fires over large areas. Geldenhuys (1994) studied the effects of these winds on the location pattern of the mixed evergreen Afromontane forests in the southern Cape, South Africa. It is the flow pattern of the wind across and around topographic barriers, which determine the flow direction of fires carried by the wind (see Chapter 5, Figure 5.1). If there are rolling hills, forests are either small or absent. If the landscape has sharp edges, such as ridges and scarps, there are many and even large forests on the leeward side (see Chapter 5, paragraph 5.1.1.1).

Similar patterns have been observed in other parts of South Africa, in Madagascar and in parts of the Congo (near Pointe Noire). The wind-fire patterns probably have similar effects on the other vegetation types in the landscape, such as woodland, fynbos and grassland.

In fuels prone to spotting, burning embers can be carried forward by the wind, causing spot fires ahead of the main fire front. During extreme fire weather with very strong winds, the fire front will increase wind speed further, and may even create "fire storm conditions", which can spot in abundance ahead of the fire front.

Fire fighters should be constantly aware of the wind conditions near a fire and preferably measure wind speed regularly with a hand

Figure 3.6. Effect of wind on fire intensity recorded in South Africa (Trollope & Tainton, 1986; Trollope & Potgieter, 1985).

Table 3.1. Modified Beaufort scale and field observation guide to estimate wind speed (based on Heikkilä et al. [1993] and adjusted by De Ronde).

Wind class	Wind speed (m/s)	Wind speed (km/h)	Field observation guide/description
1	0–1.5	0–5	Very light – Smoke rises nearly vertically, small branches sway and tall grasses sway and bend.
2	1.5–3	5–11	Light – Trees of pole size in open sway gently, leaves are loose and moving.
3	3–5	11–18	Gentle breeze – Tops of trees in dense stand sway and crested waves are formed on lakes.
4	5–8	18–28	Moderate breeze – Pole-size trees in open sway violently, dust is raised in the road.
5	8–11	28–40	Fresh – Branches are broken from trees and resisting movement when walking against it.
6	11–14	40–50	Strong – Tree damage may occur and progress is difficult when walking against the wind.
7	14–17	50–60	Moderate gale – Severe damage to trees and very difficult to walk into the wind.
8	> 17	> 60	Fresh gale – Intense stress on all exposed objects, trees and buildings.

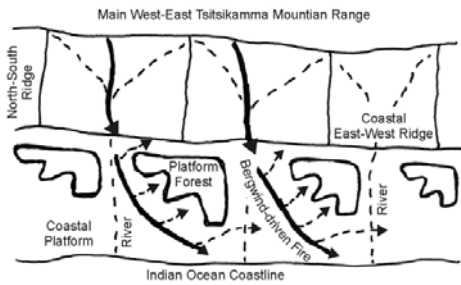
anemometer. If this instrument is not available, Table 3.1 can be used to estimate wind velocity.

3.4.2 Precipitation

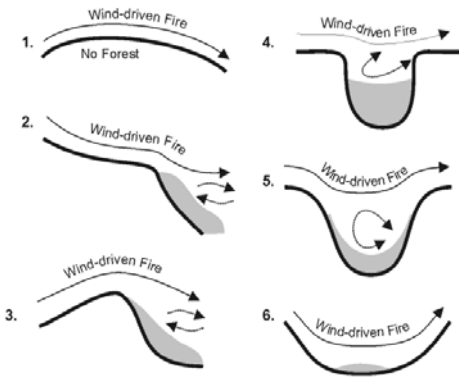
In Africa precipitation is mostly in the form of rain, but can also be in the form of dew, heavy fog, or even snow at high altitudes. Like air humidity, the occurrence of precipitation will increase fuel moisture rapidly to levels at which fires will not

burn. These conditions will persist for varying periods of time after the rain, depending on atmospheric conditions affecting the drying rate of the fuels. In the summer rainfall area of Africa, rain is normally associated with seasonal thunderstorms, which are important for the occurrence and behaviour of fires in three ways, namely rainfall, thunder-induced winds and lighting fires. The latter two aspects will be discussed later.

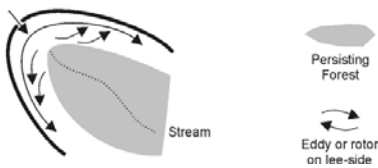
3.7 A. Typical Forest Location Pattern on Tsitsikamma Coastal Platform



B. Landscape Profiles with Remnant Forest



C. Forest in Upper Catchment or Valley



Lack of rainfall during periods of drought not only decreases fuel moisture, but considerable leaf drop occurs as a result of moisture stress. Significant rainfall may cause marked growth of short-lived grass, and in some summer seasons

this may produce above-average grass fuel loads. However, on the African continent the natural grasslands are dynamic and high summer rainfall can be followed by long dry winter periods, when curing will produce above-average available fuel and thus an increased fire hazard.

3.4.3 Air Temperature

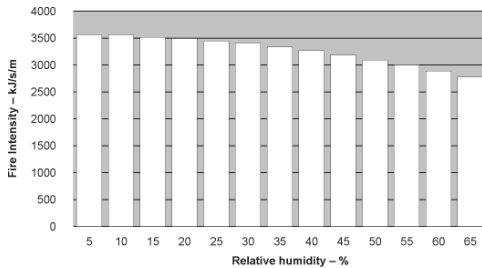
The main effect of air temperature is to reduce fuel moisture. As temperatures are normally cool during the night, fuel moisture will be higher and wildfires can be brought under control during these periods. However, as the temperature rises after sunrise, reaching a peak during the 12:00–15:00 period (if there is no sudden weather change as a result of oncoming frontal systems), this time of the day will be the time when fires reach their highest intensities. This mid-day period – when the maximum day temperatures occur – will also be the most uncomfortable period to fight fires, and fire fighters will tire more easily as dehydration becomes a problem.

3.4.4 Relative humidity

Relative humidity can be defined as “the ratio between the amount of water vapour a unit of air contains at a given temperature, and the amount of water vapour the unit of air can contain at the same temperature and pressure”. For practical purposes the effect of atmospheric pressure can be ignored, as it is very small. A high relative humidity means that there is high percentage of moisture in the air, and *vice versa*. The amount of moisture in the air affects the amount of moisture in plant fuels, and Heikkilä et al. (1993) provides the following useful rules of thumb:

Figure 3.7. Schematic view of hypothetical airflow across and around topographic barriers, to show the persistence of forest in wind-shadow areas (Geldenhuys, 1994).

3.8



- For every 20°C decrease in air temperature, the relative humidity is doubled, and for every 20°C increase in air temperature, the relative humidity is reduced by half.
- 30% relative humidity is the danger point for wildfires. When the relative humidity is above 30%, wildfires are not too difficult to control, but below 30% wildfires are generally more difficult to control.
- Relative humidity varies according to the time of the day. It is highest in the morning around dawn, and lowest in the afternoon.

The relative humidity of the atmosphere influences the moisture content of the fuel when it is fully cured (Luke & McArthur, 1978). It is positively correlated with fuel moisture (Wright & Bailey, 1982) and therefore plays an important role in controlling the flammability of fine fuels (Brown & Davis, 1973).

The effect of relative humidity on fire intensity was investigated in the Eastern Cape Province and Kruger National Park, in South Africa, and is illustrated in Figure 3.8.

Figure 3.8. Effect of relative humidity on fire intensity recorded in South Africa (Trollope & Tainton, 1986; Trollope & Potgieter, 1985).

Figure 3.9. Ground fire.



3.9

3.5 FIRE BEHAVIOUR PARAMETERS

3.5.1 Type of Fires

In forests and timber plantations, there are three types of fire according to the vertical fuel layer arrangement in which they burn. They are:

Ground fires – These are fires which burn in the organic material under the surface litter or under the soil surface, and which spread very slowly. They may burn in humus layers or old decayed stumps, which can sometimes reach a depth of several metres, particularly in following rotations of even-aged plantations where old stumps and root systems from previous rotation(s) occur. These so-called “smouldering fires” are sometimes difficult to locate, and can continue to burn unnoticed underground for many days, only to “surface” when exposed to dry wind, high air temperatures and low relative humidities (Figure 3.9).

Surface fires – These are fires that burn in surface fuels on the surface of the ground, and include litter, slash, grass and brush. Most fires begin as surface fires, which may or may not develop later into ground or crown fires,

3.10



depending on the type of fuel, topography and climatic conditions.

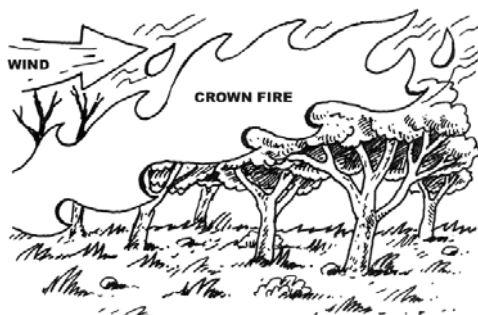
Crown fire – A fire that advances through the crown fuel layer, usually in conjunction with the surface fire. The vertical arrangement of fuel (such as “ladder fuels”), type of fuel and volume, as well as the height of tree crowns above the surface, will determine how easily crown fires can develop. Thus, crown fires can be classified according to the degree of dependence on the surface fire phase:

Passive Crown Fire (syn. Intermittent

Crown Fire) – A fire in which trees discontinuously torch, but rate of spread is controlled by the surface fire. **Active Crown Fire (syn.**

Dependent Crown Fire): A fire that advances with a well-defined wall of flame extending from the ground surface to above the crown fuel layer. Probably most crown fires are of this class. Development of an active crown fire requires a substantial surface fire, and thereafter the surface and crown phases spread as a linked unit. **Independent Crown Fire (syn. Running Crown Fire)** – A fire that advances in the crown fuel layer only. In savanna fires passive crown fires (torching

3.11



of individual trees) normally occur, while in industrial plantations active crown fires are most common (crown fires spreading fast through continuous – normally even-aged – tree crown layers).

Fires can also be classified according to their position along the fire perimeter, and their forward spread in relation to the direction of the wind.

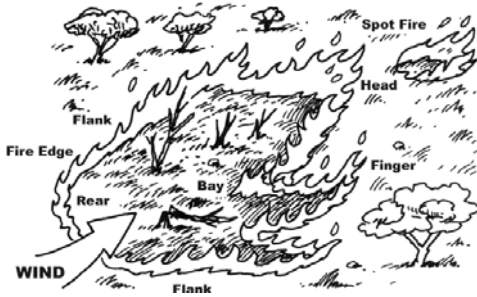
Head fire – A surface fire driven by wind and/or assisted by slope, driving the flames towards the fuel. Can be regarded as the most rapidly spreading part of a fire perimeter. Sometimes, such as in grassland, fuels are pre-heated so rapidly that large volumes of flammable gases do not mix sufficiently with oxygen to permit complete combustion. In this way, compacted lower layers of fuel may even remain unburned (Cheney & Sullivan, 1997).

Back fire (backing fire) – A surface fire burning against the wind and/or down-slope, with flames leaning backwards over the already-burned ground. This part of the fire perimeter burns slowly but efficiently and leaves little

Figure 3.10. Surface fire.

Figure 3.11. Crown fire.

3.12



residue behind. These fires also produce less smoke than head fires, and can in many cases be brought under control.

Flank fire – A surface fire burning diagonally to the direction of the wind, intermediate to a head and back fire. These (fires) form the parts of a fire perimeter which burn approximately parallel to the main direction of spread of the fire front, but do not generally burn as rapidly or as intense as a head fire, but spread faster and more intense than a back fire. Changes in wind direction can at any location change a flank fire into a head fire or back fire, along any location of the fire perimeter.

Spot fire – A fire that occurs ahead of the main fire, and is started by burning embers carried from the head fire portion of the fire perimeter, sometimes starting new fires great distances ahead of the main fire front. As spot fires sometimes jump across fire breaks, they are sometimes referred to as “jump fires”.

3.5.2 Rate of Fire Spread

The rate at which a fire perimeter expands depends on fuel, wind, topographical and weather conditions.

Fuel quantity, its vertical distribution, fuel type and continuity, will determine how fast a fire front can spread from its point of ignition, and when it will reach its *quasi-steady* state for prevailing weather conditions (Cheney & Sullivan, 1997). Factors influencing rate of spread are fuel moisture, which has a negative effect, and slope, which has a positive effect on head fires and a negative effect on back fires. Aspect is also an important factor, with dry northerly aspects in the southern hemisphere promoting the rate of spread of fires, while moist southerly aspects reduce the rate of spread of fires. Wind speed has a positive effect on the rate of spread of head fires and a negative effect on back fires burning against the wind. Air temperature has a positive effect and relative humidity has a negative effect on rate of spread. Generally, wind and fuel aeration have the most instantaneous effect on the expanding rate of a fire front.

The rate of spread of a fire is normally expressed in metres per minute, and is one of the four most important fire parameters that can be used to express fire behaviour (Andrews, 1986). The estimation of the rate of spread of fire can be made in various ways. Kruger (1977) described a simple technique for estimating fire rate of spread in fynbos communities in South Africa, where burning conditions can be very hazardous. Prior to the fire, metal stakes – one metre in length – are located vertically at grid points, spread over the area to be burnt. Thin wire is attached to each stake, using half to one metre lengths of nylon thread. The wire is then stretched to an observation point, beyond the perimeter of the area to be burnt.

Figure 3.12. Illustration of components of a fire.

At each observation point the wire is drawn over a horizontal bar approximately 1.5 m above ground level and is held taut by attaching a heavy object to the end of the wire. Each observation point is numbered and the time recorded when the fire melts the nylon thread and the heavy object falls to the ground. In this way the fire spread of the fire front from stake to stake can be measured and a mean value calculated for the fire under consideration. This method is applicable for measuring rate of spread in both surface and crown fires.

In the Eastern Cape Province of South Africa a successful procedure was developed for estimating the mean rate of spread of surface fires, burning as head or back fires (Trollope, 1983). It can also be used for crown fires. The technique involves recording the period of flaming combustion of a fire burning an area of known size and using the data in the following equation:

$$ROS = A / T \times L$$

where:

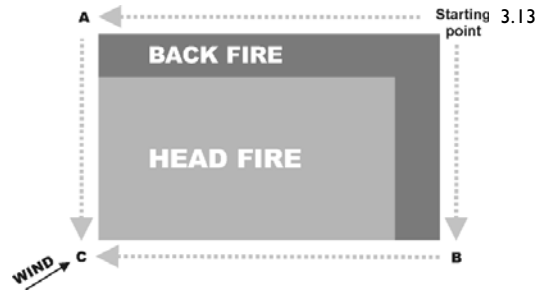
ROS = mean rate of spread – m/s

A = area burnt – m²

T = period of flaming combustion – s

L = mean length of fire front – m

The technique is best suited for measuring rates of spread in approximately square or rectangular areas, but can also be used for irregular areas, provided the perimeter and area dimensions are known. The exact procedure used for determining the rate of spread with this technique depends,



however, on the manner in which the area is burnt. A description will be given for measuring the rate of spread of a fire burning a square area that has been set alight according to the normally accepted modus operandi. The procedure for estimating the rate of spread of head fires is illustrated in Figure 3.13.

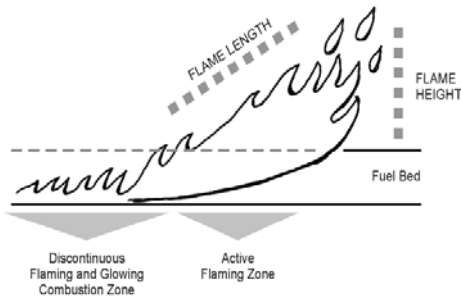
Commencing at the starting point, two back fires are simultaneously initiated along the two leeward sides to corners A and B of the area being burnt. The back fires are allowed to burn until the situation is deemed safe, at which time a head fire is initiated by ring firing the windward sides from points A and B to point C as swiftly as possible. The mean length of fire front that is used in the formula is equal to half of the initial total length of fire front along the windward sides. This is because when ring firing an area, the length of fire front tends to zero as the burnt area increases. In calculating the area burnt as a head fire, a correction must be made for the portion that was initially burnt as a back fire along the two leeward sides.

3.5.3 Flame Length and Flame Height

The difference between flame length and flame height is illustrated in Figure 3.14.

Figure 3.13. Procedure for measuring the rate of spread of a head fire when the wind is blowing diagonally across the area to be burnt.

3.14



In the absence of wind and slope, flame length and flame height are equal, but wind and/or slope have the effect of tilting the flame towards the unburned fuel, and thereby reducing flame height, while flame length remains unaffected. Flame height is another one of the four main fire behaviour parameters to be considered (Andrews, 1986), and is an important parameter for predicting the height of crown scorch in the canopy of trees.

3.5.4 Fire Intensity Parameters

The two most important ways to express fire intensity are Fireline Intensity (kW/m or kJ/s/m) and Heat per Unit Area (kJ/m²). Fireline intensity can be regarded as the heat released per second from a metre-wide section of fuel extending from the front to the rear of the flaming zone (Byram, 1959), and is equal to the product of the fuel load, heat yield and the rate of spread of the fire front, i.e.:

$$I = H \times w \times r$$

where:

I = fire intensity – kJ/s/m

H = heat yield – kJ/kg

w = mass of available fuel – kg/m²

r = rate of spread of the fire front – m/s

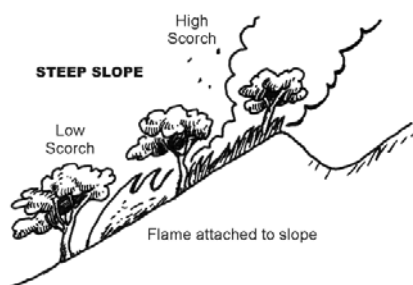
The heat yield that can be used for grass fuels in African grasslands and savannas for head fires is 16 890 kJ/kg and for backfires is 17 781 kJ/kg (Trollope, 1983). Heat per unit area is the heat released from a square metre of fuel while in the flaming zone, and is equal to the reaction intensity times the residence time. Fireline intensity and heat per unit area are regarded as two of the foremost important fire behaviour parameters describing fire behaviour (Andrews, 1986). However, research conducted in southern and east African savannas has shown that fireline intensity as defined by Byram (1959) is the most biologically meaningful fire behaviour parameter to use for ecological purposes. This is because it has been found to be significantly correlated to the response of vegetation to fire in African plant communities (Trollope & Tainton, 1986; Trollope et al., 1990). It should be noted though that Trollope (1981) proposed that fire line intensity should be expressed as kJ/s/m instead of kW/m. This is because it is conceptually more meaningful to express fire intensity in terms of the rate of release of heat energy as originally proposed by Byram (1959) rather than in units of power as required by the metric system for expressing physical phenomena in numerical units. However, Rothermel (1972), Andrews (1986), Andrews and Chase (1986) and Andrews and Bevins (2000) continue to use kW/m units to express Fireline Intensity.

3.5.5 Torching, Scorching and Spotting

Torching – Occurs when individual trees are ignited, but there is insufficient wind to sustain a crown fire. A torching tree may give rise to burning embers being lifted straight

Figure 3.14. Active flaming zone, in relation to discontinuous flaming and glowing combustion (Andrews, 1986).

3.15



up and then carried away by the prevailing wind to start spotting fires elsewhere. This situation is always a warning sign for fire fighters that any increase in wind speed can start a crown fire in plantations or forests where there is a continuous crown canopy cover.

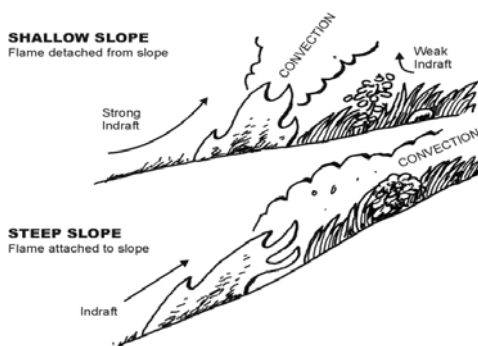
Scorching – This is when tree needles or leaves in tree crowns die as a result of the heat radiated from the flames of a surface fire. Scorch height is the height to which scorching (not fuel consumption) occurs in tree crowns, vertically measured from the soil or forest floor surface. A useful rule of thumb is to use the 1:6 flame height-to-scorch height ratio as a measure to estimate scorch height potential, when prescribed burning is applied. The use of air temperature and wind speed adjustments, to arrive at an even more accurate scorch height prediction, can provide a more accurate scorch height estimation, and this will be discussed in more detail in Chapter 12.

In the case of a fire spreading uphill on a steep slope, scorching is always greater towards the top of the catena than on the lower slopes, as is illustrated in Figure 3.15.

Figure 3.15. Scorching conditions on a steep slope (Andrews & Chase, 1986).

Figure 3.16. Flame detached from a shallow slope and flames attached to a steep slope (Andrews & Chase, 1986).

3.16



Spotting – This is one of the most dangerous characteristics of major wildfires in terms of fire suppression. It can be very dangerous to attack a head fire from the front where spotting occurs, and in many cases lives of firefighters have been lost where this occurred and firefighters were trapped (e.g. ten firefighters died in a fire near Sabie, Mpumalanga Province, South Africa, during 1994).

In the case of long distance spotting, burning embers are carried several km from the main fire front, to ignite new fires far ahead of the main burning fires. Chances are that this spotting will normally be on the right flank of the advancing fire front because of the tendency of the wind-velocity vector to advance in a clockwise direction with increasing height (Davis, 1959). Often the direction of the upper winds is different from the direction of the surface wind, which can cause further deviation from the direction of maximum fire spread.

3.5.6 Topography and Fire Perimeter Forms

The steepness of a slope can have a pronounced effect on fire behaviour, as the degree of steep-

ness will determine the extent to which fuel is dried out before the fire front. The attachment of a slope can best be illustrated as in Figure 3.16.

Aspect can also have a significant effect on fuel drying rates and subsequent fire behaviour, with northerly aspects (in the southern hemisphere) being more exposed to direct sunlight, and normally receiving less rain on the rainfall shadow of mountain ranges. Southerly aspects, generally speaking, have less direct sunlight exposure, and vegetation thus retains moisture for longer periods. Rainfall is also significantly higher on southerly slopes than on northerly slopes, and because of that, vegetation growth is also greater on these aspects than on northerly slopes, which have a much lower depth profile and also have much drier plant fuels. Field observations show that this variation is very marked in fynbos vegetation communities on the mountain ranges in the Eastern and Western Cape Provinces in South Africa.

Slope significantly influences the forward rate of spread of surface fires, by modifying the degree of preheating of the unburned fuel immediately in front of the flames. In a head fire, this is achieved (as with wind) by changing the flames to a very acute angle and, with slopes exceeding 15–20°, the flame propagation process involves almost continuous flame contact. Conversely, a down slope decreases the rate of spread of surface head fires (Luke & McArthur, 1978), and at low wind speeds has the effect of converting a head fire into a back fire. In Australia a general exponential relationship is used for estimating the effect of

slope on the rate of spread of surface head fires (Cheney, 1981). The equation is:

$$R = Ro e^{bx}$$

where:

R = rate of spread – m/s

Ro = rate of spread on level ground – m/s

e = exponential function

b = 0.0693

x = angle of the slope – degrees

This relationship should not be used for gradients greater than 30° because the distribution of the surface fuel usually becomes discontinuous on steep slopes (Cheney, 1981).

Experience gained in the USA indicates that the increasing effect of slope on the rate of spread of head fires doubles from a moderate slope (0–22°) to a steep slope (22–35°) and doubles again from a steep slope to a very steep slope (35–45°) (Luke & McArthur, 1978). The effect of wind and/or slope also has a marked effect on fire shape (also called the form of the fire perimeter), and a change in wind speed in particular will change the length-to-width ratio of the fire perimeter significantly. This can be illustrated as follows:

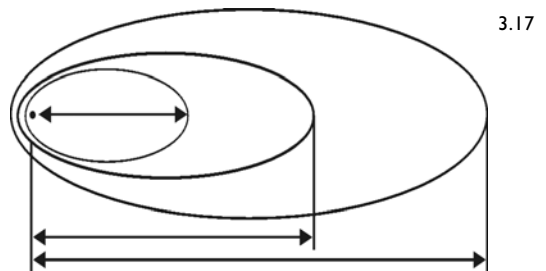


Figure 3.17. Typical fire perimeter shape of a wind-driven fire (Andrews, 1986).

3.6 FIRE BEHAVIOUR PREDICTION WITH BEHAVEPLUS

3.6.1 Using BEHAVE and BehavePlus

The BehavePlus Fire Modeling System replaces the 1984 BEHAVE Fire Behaviour Prediction and Fuel Modeling System (Andrews, 1986; Andrews & Chase, 1986; Burgan & Rothermel, 1984) with a new computation engine and graphic user interface. However, for Custom Fuels Models, the NEWMDL and TSTMDL programmes of the FUEL subsystem still have to be used for fuel model development and testing (Burgan & Rothermel, 1984). For Africa, the use of locally developed fuel models is recommended, as BehavePlus does not allow the user to define a custom fuel model via direct input of fuel characteristics (Andrews & Bevins, 2000).

BEHAVE and BehavePlus have been used widely internationally to predict fire behaviour before applying prescribed burning and to predict wild-fire behaviour. BehavePlus provides a user-friendly application for fire management purposes on a much wider scale in Africa south of the Sahara than is presently the case. The BehavePlus programme, Users' Guide and Tutorial, can directly be downloaded from the <http://www.fire.org> website.

3.6.2 Selecting Fuel Models

Before the BEHAVE fire behaviour prediction programme can be used, it is necessary to select the correct fuel model(s), which represent the fuels found in the area for which the prediction is required. Only some North American models (USA – NFFL) are useful under African conditions, for three reasons:

- African grasslands have in most cases a very pronounced curing period after the summer rainfall, and is subsequently classified as a “dynamic” fuel because this process changes all green vegetation in these systems to dead (available) biomass.
- Both African forests and woodlands differ significantly from those found in the USA, particularly with regard to species, type as characteristics of fuel, fuel loading as well as distribution.
- The species composition, silvicultural regimes and fuel characteristics of even-aged timber plantations in southern Africa have their own unique fuel features.

The only fuel models from the NFFL set that are recommended for even-aged industrial timber plantations, growing under African conditions, are the three models for Slash Fuels, namely:

- Model 11 – Light logging slash
- Model 12 – Medium logging slash
- Model 13 – Heavy logging slash

The above models should be used to predict fire behaviour in plantations after clearfelling and timber exploitation, by identifying whether the slash residual can be classified as “light”, “medium” or “heavy”. For other industrial plantation and natural vegetation types, some models have been developed for local conditions, but most of them only for specific regions. A selection of these fuel models has been summarised in Table 3.2.

The fuel models used in Table 3.2 have to be entered in BehavePlus as follows:

Table 3.2. A selection of (custom) fuel models that can be used for African conditions.

Description of fuel	Model 15	Model 16	Model 17	Model 18	Model 19	Model 20	Model 21	Model 22
1 Hr fuel load *	4.0	0.87	3.00	0.27	13.11	28.22	6.77	9.01
10 Hr fuel load *	0.95	0	0	0	1.41	1.01	3.00	0
100 Hr fuel load *	0.12	0	0	0	0	0.40	1.79	0
Live herb fuel load *	5.0.	0.87	3.00	5.02	0.11	0.02	0.09	0
Live woody fuel load *	2.24	0	0	0	01	0	0	0
1 Hr surface area-to-volume ratio (SAV)**	7215	4921	4921	4921	6562	6562	8202	8202
Live herb SAV**	5900	4921	4921	4921	4921	4921	4921	0
Live woody SAV**	4920	0	0	0	0	0	0	0
Fuel depth (m)	1.40	0.20	0.50	0.60	0.073	0.143	0.454	0.046
Fuel moisture extinction (%)	34	13	13	13	30	29	14	31
Dead fuel heat content***	20000	18488	18488	18988	17989	17989	21438	20985
Live fuel heat content***	20000	18488	18488	18988	17989	17989	21438	20985

* = tons/ha; ** = square metre/cubic metre; *** = kilojoules per kilogram

1. Load the Fuel Modelling Worksheet by selecting **File, New Worksheet**.
2. In the Worksheet that is displayed, enter the fuel model parameter values. Alternatively, the fuel model parameters can be initialised with an existing fuel model, by clicking on **Initialize** from a Fuel Model button.
3. Select the **File, SaveAs, Fuel Model Menu** item.
4. Select the **Fuel Model Folder, Fuel Model File Name** and **Fuel Model Description**. Click on the **OK** button.

5. Test the new fuel model for a range of environmental conditions. Do this by loading the **SurfaceBasic** or **SurfaceSimple** worksheet, and by comparing the new fuel model to existing fuel models for a range of conditions (Andrews & Bevins, 2000).

The following models (see Table 3.3) have been selected from some region-specific fuel model files (Van Wilgen & Richardson, 1985) and de Ronde (various regional plan publications) for use in Table 3.2 .

3.6.3 Using the SURFACE and SIZE Modules

Once a suitable fuel model (or fuel models) has been selected (or created and tested under the NEWMDL and TSTMDL programmes, Burgan & Rothermel, 1984) for BehavePlus, it is now possible to continue with the fire behaviour prediction procedures. The fuel data are now entered (see BehavePlus Users' Guide) and one now proceeds to the **SURFACE** module.

The **SURFACE** module can calculate up to 14 different fire behaviour or input-related values. The primary outputs in this case will be rate of spread, heat per unit area, fireline intensity, flame length and reaction intensity. Inputs to the **SURFACE** module include values that specify fuels, fuel moisture, wind speed, wind direction and slope steepness. This module mainly replaces the old **DIRECT** module, and is very useful for basic fire parameter calculations.

The **SIZE** module calculates seven fire size values, which will provide estimates of the fire front spreading distances over time, as well as

characteristics of the fire front perimeter as the fire spreads. This module can run independently where all input values are entered by the user, or be linked to the **SURFACE** module. Inputs to the **SIZE** modules include effective rate of spread and elapsed time in which the fire has been spreading from its ignition point.

3.6.4 Predicting SPOT, SCORCH and MORTALITY

The **SPOT** module calculates three spotting distance values. The output selection includes spotting from torching trees, spotting from a burning pile (e.g. a slash pile) or spotting from a wind-driven surface fire (such as grassland). **SPOT** can be used independently, or linked to the **SURFACE** module. Input will include topographical information and tree data (where applicable).

The **SCORCH** module calculates the scorch height, based on the input of either flame length or fireline intensity. It can also be run independently, or be linked to the **SURFACE** and **SPOT** modules. The output only provides the scorch height.

The **MORTALITY** module calculates the probability of tree mortality as well as three intermediate values. Probability of mortality is calculated from tree height, crown ratio and scorch height. It can also run independently, but if both **SCORCH** and **MORTALITY** are selected, the modules are linked.

3.6.5 Using BehavePlus for Prescribed Burning

Predicting fire behaviour for a planned prescribed burning exercise – whether in a fynbos, grassland or plantation fuel base – for fuel reduction or

Table 3.3. Description of fuel models used for Table 3.2.

Fuel Model	Description
15	Pristine (mature) fynbos without invaders (Van Wilgen et al., 1985)
16	Intensely grazed natural grassland in the Mpumalanga Highveld (De Ronde, 1998a)
17	Natural grassland in the Mpumalanga Highveld, more than one curing season old (De Ronde, 1998b)
18	Wetland grassland in the Mpumalanga Highveld (De Ronde, 1998b)
19	Even-aged pine stands with partly-closed crown canopy, approximately 6–8 years old in KwaZulu-Natal (De Ronde, 1997)
20	15–18 years old even-aged <i>Pinus elliottii</i> and <i>Pinus patula</i> stands with closed crown canopy in Mpumalanga (De Ronde, 1996)
21	2–3 year old <i>Eucalyptus</i> stands, second rotation with slash unburned (De Ronde, 1996)
22	Mature <i>Eucalyptus</i> stands, older than 5 years (De Ronde, 1996)

fire protection purposes, should be conducted the day before the burning is planned. The SURFACE module of BehavePlus must be used first, with input of the required fuel model data (or a saved Custom Fuel Model), fuel moisture data, weather and topographical data (with or without the use of the MAP option to calculate percentage slope), time, and fire spread direction information. The output will then be in the form of a fire behaviour parameter data that can be used to obtain some estimates of the fire behaviour that can be expected on the planned day of the burn.

The SCORCH module, linked to SURFACE, can also be used to predict the scorch height in the case of prescribed burning application inside plantation stands. Obviously the MORTALITY or SPOT modules cannot be used here, as both should never occur when fire is applied inside plantations!

3.6.6 Using BehavePlus for Predicting Wildfire Behaviour

The SURFACE module can be used to provide basic fire behaviour prediction data, but for this

Table 3.4. The range of values of the dependent and independent variables used in the development of the fire intensity model in South Africa (Trollope, 1983; Trollope & Potgieter, 1985).

Variable	Mean	Minimum	Maximum
Fuel load (kg/ha)	3847	1152	10500
Fuel moisture (%)	32.1	7.5	68.8
Air temperature (°C)	23.8	14.3	35.8
Relative humidity (%)	36.6	4.2	82
Wind speed (m/s)	2.6	0.3	6.7
Fire intensity (kJ/s/m)	2566	136	12912

purpose the SIZE module should be added to estimate how long a wildfire will take to cover a certain distance, to reach a specific fire break, or a plantation. This is particularly useful in the case of predicting fire spread where large areas are covered by natural grassland or savanna, and in fynbos-covered mountains. The MAP option can be used to insert slope parameters. A more sophisticated fire simulation programme that can be used is FARSITE, but then a compatible GIS base of the terrain will be required, as well as hourly weather data and fuel models that cover the whole area involved (Finney, 1996).

The SPOT option is useful to estimate spotting potential when a fire is spreading uncontrolled in a specific fuel and specified terrain under known weather conditions, and is of particular value to determine what the probability will be that certain natural or artificial barriers will stop a wildfire. The SCORCH and MORTALITY modules (linked to the SURFACE module) can also be used

to assist in predicting wildfire impact in woodlands or plantations. However, experience in southern Africa indicates that the MORTALITY option is not very useful in even-aged plantations, because it only covers a few pine species that occur in the sub-continent.

3.7 OTHER FIRE BEHAVIOUR MODELS

As indicated in the previous section, it is clear that fuel, atmospheric and topographical factors have a significant effect on fire behaviour. These effects have been quantified in the form of fire behaviour models, which can be used in formulating guidelines for controlled burning. For African grasslands, some specific models have been developed.

3.7.1 Fire Intensity Models

Based on research conducted in the Eastern Cape Province and in the Kruger National Park in South

Africa (Trollope, 1983; Trollope & Potgieter, 1985) a fire intensity model was developed, using a multiple regression analysis for surface head fires, burning in grassland and savanna areas. The model was based on the effects of fuel load, fuel moisture, relative humidity and wind speed on fire intensity. Air temperature was considered, but not included in the model because it is significantly correlated with relative humidity. Slope was also excluded, because the experimental fires were all applied to relatively flat terrain. The fire intensity model was developed under the following range of values for the dependent and independent variables (see Table 3.4).

The results of the multiple regression analysis are presented in Table 3.5.

The results in Table 3.5 show that the independent variables all had a statistically significant effect, and that they accounted for 60% of the variation in fire intensity. Fuel load and fuel moisture influenced fire intensity to the greatest degree, whereas relative humidity and wind speed

had a significant but far smaller effect. The multiple regression equation for predicting fire intensity is:

$$FI = 2729 + 0.8684 x_1 - 530 \sqrt{x_2} - 0.907 x_3^2 - 596 1/x_4$$

where:

FI = fire intensity – kJ/s/m

x_1 = fuel load – kg/ha

x_2 = fuel moisture – %

x_3 = relative humidity – %

x_4 = wind speed – m/s

The regression equation is based on the following statistics:

Number of cases = 200

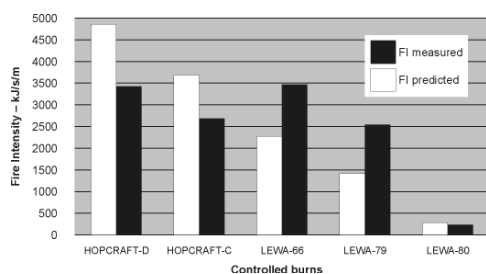
Multiple correlation coefficient (R) = 0.7746
(P < 0.01)

Coefficient of determination (R²) = 0.6000

Table 3.5. The effects of fuel load, fuel moisture, relative humidity and wind speed on fire intensity expressed as a percentage (n = 200).

Independent Variable	Transformation	Effect (%)	Significant
Fuel load	x	42.7	$P \leq 0.01$
Fuel moisture	$\sqrt{x}$	14.7	$P \leq 0.01$
Relative humidity	x^2	1.0	$P \leq 0.02$
Wind speed	$1/x$	1.6	$P \leq 0.02$
Total		60.0	

3.18



The model was tested with independent fire behaviour data and was found to be highly significant ($r = 0.7486$; $DF = 33$; $P < 0.01$), accounting for 56% of the variation in fire intensity. By normal statistical standards, this coefficient of determination is rather low. Generally, regression equations are used only for predictive purposes, when the coefficient of determination accounts for at least 95% of the variation in the dependent variable. However, experience gained during this research indicates that it is virtually impossible to attain these levels of precision when modelling such a complex phenomenon as fire behaviour. The fact that the results from the statistical analyses were significant, conceptually meaningful and logical, indicates that these results can be used as a guide for predicting the behaviour of fires. Therefore, if the results are used in this context, it is firmly believed that they can serve as a useful guide for fire management purposes. It should never be forgotten though that fire is a highly complex phenomenon that is very difficult to model precisely.

The aforementioned fire intensity model, developed in South Africa, was tested in the central highlands of Kenya in the overall range type classified as “Scattered Tree Grassland:

Acacia-Themedra” by Edwards and Bogdan (1951). This range type is the most extensive vegetation type at intermediate elevations in Kenya and is characterised by flat-topped *Acacia* trees, widely scattered in a uniform grassland typical of East African savannas. Measured and predicted fire intensities were obtained from five controlled burns applied under widely differing atmospheric conditions and the results are presented in Figure 3.18.

The results presented in Figure 3.18 generally concur with fire behaviour data obtained in the savannas of southern Africa, and show that the fire intensity model was able to predict the difference between high and low intensity fires. However, the results show that the model was not sensitive enough for differentiating between smaller differences in fire intensity. This is to be expected with a coefficient of determination (R^2) of 0.60, which accounts for only 60% of the variation in fire intensity caused by the independent variables. Nevertheless, as in the case of southern African savannas, the fire intensity model still provided a satisfactory basis for formulating guidelines for controlled burning based on fire intensity.

Fire intensity has also been modelled by Van Wilgen and Wills (1988) in the savanna areas of northern KwaZulu-Natal, in South Africa, using the fire spread model developed by Rothermel (1972) in the USA. The system uses fuel models, which describe the fuel properties of the dominant vegetation as inputs. Fuel data were collected in *Acacia* savanna dominated by *Themeda triandra* and *Cymbopogon excavatus* and the mean fuel load was 3800 kg/ha, of which 82% was dead grass.

Figure 3.18. The fire intensity of controlled burns applied as head fires in the central highlands of Kenya (Trollope & Trollope, 1999).

Fire intensities ranged from 194 to 5993 kJ/s/m in ten experimental burns and the relationship between the observed and the predicted was $r = 0.9074$ (DF = 8; $P < 0.01$). The use of this system in practice is facilitated by sets of either BEHAVE or BehavePlus computer programmes.

3.8 BEHAVIOUR OF DIFFERENT TYPES OF FIRES

One of the components of the fire regime is the type of fire. Its inclusion as part of the fire regime is justified on the basis that different types of fires behave differently and have contrasting effects on the vegetation. In the grassland and savanna areas, surface fires burning as head and back fires are the most common types of fire. The behaviour of surface fires, burning with and against the wind, were investigated by Trollope (1978) in savanna areas of the Eastern Cape Province, South Africa, in order to obtain greater clarity on the mechanisms involved in the different effects of these types of fires on the vegetation. The parameters that were used for comparing the behaviour of head and back fires were rate of spread, fire intensity, flame height and fire temperature.

3.8.1 Rate of Spread

Differences in the rate of spread was one of the most striking features of the behaviour of head and back fires, and the maximum, minimum and mean rates of spread for these two types of fires are presented in Table 3.6. The results in Table 3.6 show that, on average, head fires were seven and a half times faster than backfires in this study. Furthermore, the standard errors of the mean rate of spread of the two types of fires show that the head fires were far more variable than the back fires, and were therefore more significantly influenced by the environmental variables prevailing at the time of the burns.

3.8.2 Fire Intensity

The mean, minimum and maximum intensities of surface fires burning with and against the wind are presented in Table 3.7.

The results in Table 3.7 bear a close relationship to those for rate of spread of head and back fires because this parameter is an important component in the calculation of fire intensity.

The head fires were on average approximately seven times more intense than the back fires. The intensity of the head fires was far more variable

Table 3.6. The rate of spread of head and back fires, recorded in controlled burns in savanna vegetation in the Eastern Cape Province of South Africa. Data expressed in metres per second (m/s).

Type of Fire	Number	Mean	Minimum	Maximum
Head fire	10	0.15 + 0.03	0.04	0.35
Back fire	9	0.02 + 0.002	0.01	0.03

than that of the back fires. They ranged from very cool fires to extremely hot fires, whereas the back fires were all very cool. Therefore, as in the case of rate of spread, the intensity of head fires was far more significantly influenced by the environmental conditions prevailing at the time of the burn than the back fires.

3.8.3 Flame Height

The mean, minimum and maximum flame heights of the head and backfires are presented in Table 3.8. The data in Table 3.8 clearly illustrates the greater height of flames occurring in head fires than backfires. The wide range in the height of flames of head fires indicate the potential variability of this type of fire in comparison to back fires, as influenced by environmental variables.

3.8.4 Fire temperature

Temperatures were measured during the head and back fires at ground level, and one metre above the grass canopy.

At ground level, the majority of back fires were hotter than the head fires. At the grass canopy, the maximum temperatures of both head and back fires were generally higher than those at ground level. However, the majority of back fires were hotter at this level. At one metre above the grass canopy, head fires were considerably hotter than back fires.

Thus the overall behaviour of these types of fires is that back fires are generally hotter at ground level, whereas head fires are generally hotter above the canopy of the grass sward (Trollope, 1987).

Table 3.7. The intensity of head and backfires recorded in controlled burns in savanna vegetation in the Eastern Cape Province of South Africa. Data expressed in kilojoules per second per metre (kJ/s/m).

Type of Fire	Number	Mean	Minimum	Maximum
Head fire	10	1359 + 327	338	3557
Back fire	9	194 + 18	87	268

Table 3.8. The flame height of head and back fires recorded in controlled burns in savanna vegetation in the Eastern Cape Province of South Africa. Data expressed in metres (m).

Type of Fire	Number	Mean	Minimum	Maximum
Head fire	10	2.8 + 0.4	1.2	5.0
Back fire	9	0.9 + 0.1	0.5	1.5

3.8.5 Conclusions

Notwithstanding the difficulties of studying fire behaviour, the information that has been presented emphasises the importance of this aspect of fire ecology. The identification of fire intensity and flame height as ecologically meaningful parameters describing the behaviour of vegetation fires has enabled the quantification of fire behaviour, and has provided a means of quantifying the effects of fire on the biotic components of grassland and savanna ecosystems. The development of a simple fire intensity model, based on easily measured environmental factors, has also provided an objective means of formulating quantitative guidelines, involving fuel loads, fuel moisture, air temperature, relative humidity and wind speed for controlled burning in African grasslands and savannas. The comparisons of the behaviour of head and back fires also clearly illustrates the differences between these two types of fires. The contrasts in fire intensity, flame height and fire temperatures have great biological significance, as they indicate the rate and vertical level at which heat energy is released during head and back fires, and thus provide a greater understanding of the effects of fires on the ecosystem. The contrasting behaviour of head and back fires is also pertinent to the formulation of safety procedures for controlled burning. The fire behaviour data illustrate how – by merely altering the type of fire – a burn can be converted from a cool fire into a raging inferno under the same fuel and atmospheric conditions. These results provide the rationale behind the safety procedures that are incorporated in the *modus operandi* for controlled burning that will be discussed later. Great strides have been

made in the study of fire behaviour, and it is now possible to formulate realistic guidelines for land users in terms of type and intensity of fires.

3.9 SMOKE DEVELOPMENT AND POLLUTION

3.9.1 Predicting Smoke Development

Smoke varies greatly in quantity, form, thickness, brightness and colour, and it is in most cases difficult to predict what characteristics smoke will have as a result of a particular fire. Experienced firefighters can “read” smoke while approaching a wildfire scene, and they are sometimes even experienced enough to explain to colleagues what fuel is being consumed and what fire behaviour can be expected. However, unfortunately, smoke development prediction models for African conditions still have to be developed.

Smoke emerges in various forms of brightness and colour, depending on lighting, chemical composition, moisture content and rate of combustion of the burning fuels. It may vary in colour from white to black with all sorts of bluish and other shades in between. Smoke may appear in columns, or in almost any shape, depending on weather conditions and the stability of the air. During wildfire conditions, knowledge of smoke-rise and drift can assist in identifying forest fire characteristics, such as fire perimeter size, rate of fire spread and containment potential (Davis, 1959).

Smoke from wildland fires can range from a negligible to a very significant cause of air pollution, resulting in economic losses, depending on the lifting, dilution rate, and trajectory of the plume. Effects should be considered individually and

may include the cost of highway accidents due to decreased visibility, the closure of airports re-routing air traffic, closures or slowdown of manufacturing operations by air quality regulations and costs, plus the damage of other undetected fires because of reduced visibility (Chandler et al., 1991). It thus plays an important role in the decision-making process when serious wildfires occur, and this aspect should not be neglected. Experienced fire managers will take the necessary action when smoke from a wildfire is threatening public operations and their well-being.

Where airports and highways may be affected by the smoke from wildfires, fire managers should predict the direction of smoke development, based on experience and predicted weather conditions; and in particular evaluate the expected wind direction and air stability. Local public authorities concerned should be alerted as soon as possible of any threatening smoke potential, to avoid (possible) serious accidents. In South Africa in particular, road accidents have caused serious loss of life almost every year since 1990, as a result of runaway grassland fires in the Highveld region of South Africa. Potential danger to the public arising from raging wildfires can be minimised through the use of fire behaviour models like BehavePlus. Predictions of the rate and size of spread of the wildfire, together with local experience, can be used to formulate appropriate public safety strategies.

Computer-based wildfire spread simulation can also be used to advantage to calculate the predicted spread of a wildfire and subsequent smoke development – for instance, when the

smoke of a fire front is expected to reach a strategic road, airport or railway line. This will make it possible to warn the responsible authorities in advance, so that they can take precautionary action if and when required.

3.9.2 Smoke Management

There is very little that can be done with smoke from wildfires, apart from precautionary measures, to pre-empt danger to the public as described in the previous section. In the case of prescribed fires, smoke does generally not develop to the same extent as wildfires, but nevertheless the following measures should be taken to minimise the aforementioned potential dangers to the public:

- Apply controlled burns when atmospheric conditions are ideal for the rapid dispersion of smoke. Ideally, the atmosphere should be thermally neutral to slightly unstable to enable smoke to rise and disperse, but not unstable enough to jeopardise the safe application of the controlled burns.
- Exercise caution when controlled burns are applied adjacent to or up-wind of smoke-sensitive areas. Ideally, controlled burning should be applied when the wind will carry the smoke away from public roads, airports and populated areas. Generally controlled burning should not be conducted if smoke-sensitive areas are within one kilometre downwind of the proposed burn.
- Reduce residual smoke by applying aggressive “mopping-up” operations after controlled burns to extinguish all remaining fires.

- Use test fires to confirm the potential behaviour of the smoke in terms of direction of spread and rate of dispersion.
- Use backfires when possible with controlled burning because they produce less smoke, consume dead fuels more efficiently and therefore restrict visibility less. The disadvantage of using backfires is that they move slower and are therefore more expensive to apply.
- Apply controlled burns during the middle of the day when atmospheric conditions are less stable and therefore more favourable for the dispersion of smoke. Where possible, avoid burning at night because temperature inversions usually occur in the atmosphere closest to ground level, resulting in very stable atmospheric conditions and therefore very limited dispersal of smoke.

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4

FIRE EFFECTS ON FLORA AND FAUNA

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4.1 FIRE EFFECTS ON FLORA

4.1.1 Fire Effects in Savannas and Grasslands

Research on the effects of fire has been conducted throughout the grassland and savanna areas of Africa since the early period of the 20th century and considerable progress has been made in determining the effect of the different components of the fire regime on grassland and savanna communities, i.e. the effects of the type and intensity of fire and the season and frequency of burning.

4.1.1.1 Type of Fire

The most common types of fire in grassland and savanna areas are surface fires (Trollope, 1983) burning either as head or back fires. Crown fires do occur in savanna, but only under extreme fire conditions. Generally, under these conditions, they occur as passive crown fires characterised

by the “torching” of individual trees rather than active crown fires that are sustained by more abundant and continuous aerial fuels. The significance of the effect of type of fire on plants is that it determines the vertical level at which heat energy is released in relation to the location of bud tissues from which meristematic sites the plants recover after burning.

The effect of type of fire on the regrowth of grass

Trollope (1978) investigated the effects of surface fires, occurring as either head or back fires, on the grass sward in the arid savannas of the Eastern Cape of South Africa. The results showed that back fires significantly ($P < 0.01$) depressed the re-growth of grass in comparison to head fires because a critical threshold temperature of approximately 95°C was maintained for 20 seconds longer during backfires than during head fires. It was also found that more heat was released at

ground level during the back fires compared to the head fires, therefore the shoot apices of the grass plants were more adversely affected during the back fires than during the head fires.

The effect of type of fire on bush

Bush is very sensitive to various types of fires because of differences in the vertical distribution of the release of heat energy. Field observations in the Kruger National Park and in the Eastern Cape indicate that crown and surface head fires cause the highest topkill of stems and branches, as compared with back fires. Unfortunately there are only limited quantitative data to support these observations. Research results were obtained from a burning trial at the University of Fort Hare in the False Thornveld of the Eastern Cape (arid savanna) in South Africa, where a field-scale burn was applied to an area of 62 hectares to control bush encroachment. The effect of surface head and back fires on the topkill of stems and branches of bush is presented in Table 4.1. The data were collected in two-metre wide belt transects laid out in the areas burned as head and back fires.

The majority of the trial area was burned as a head fire, and the results in Table 4.1 indicate that the phytomass of bush was reduced by 75% in the area burned as a head fire, in comparison to 42% in the area burned as a back fire. The explanation for this is that the flame height of head fires can be up to three times greater than for back fires, resulting in higher temperatures being generated above ground level (Trollope, 1978).

Therefore, the above-ground growing points of these plants, which are located in the canopies of the trees and shrubs, are subjected to greater heat loads and resultant damage during head fires than during back fires. This clearly illustrates the effects different types of fire have on tree and shrub vegetation.

Similar results were obtained in the Scattered Tree Grassland: *Acacia-Themeda* (Edwards & Bogdan, 1951) range type by Trollope and Trollope (1999) on the effects of head and back fires on the topkill of bush.

The results indicate that head and back fires have different effects on the topkill of bush, with

Table 4.1. The effect of surface head and back fires on the topkill of bush in the False Thornveld of the Eastern Cape in South Africa, expressed as the reduction in the number of tree equivalents – TE (TE = tree or shrub one metre high).

Type of Fire	Transect	Bush Phytomass TE/ha	Bush Phytomass TE/ha		Reduction %
	Length (m)		Before	After	
Head Fire	940	2	3525	888	75
Back Fire	560	2	3407	1991	42

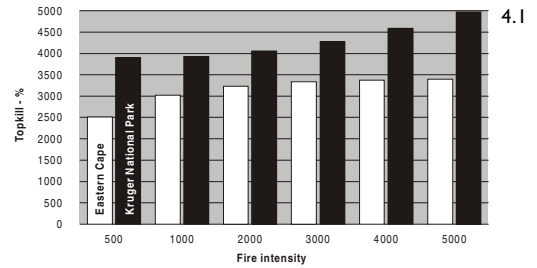
head fires generally causing a greater topkill than back fires. Initially, both types of fires cause a high topkill of stems and branches when the bush is short, but as the trees and shrubs increase in height, back fires cause a lower topkill compared to head fires.

This trend becomes more pronounced with trees greater than two metres in height. The reason for this is that head fires generate greater flame heights than back fires, thus resulting in the fire-susceptible growing points of taller trees and shrubs, being above the flaming zone of combustion during back fires, as compared to head fires.

4.1.1.2 Fire Intensity

Fire intensity refers to the release of heat energy per unit time per unit length of fire front (kJ/s/m) (Byram, 1959). There have been very limited attempts in African savannas and grasslands at quantitatively measuring the intensity of fires and relating fire intensity to the response of herbaceous and woody plants in terms of mortality and changes in physical structure. Such research appears to be limited to studies conducted in the savanna areas of South Africa.

The effect of fire intensity on the recovery of the grass sward after burning was investigated in the arid savannas of the Eastern Cape. After a series of fires ranging in intensity from 925 to 3326 kJ/s/m (cool to extremely intense) there were no significant differences in the recovery of the grass sward at the end of the first or second growing seasons after the burns (Trollope & Tainton, 1986), leading to the conclusion that fire intensity has no significant effect on the recovery



of the grass sward after a burn. This is a logical result, as otherwise intense fires would not favour the development and maintenance of grassland.

The effect of fire intensity on bush has been studied in the arid savannas of the Eastern Cape (Trollope & Tainton, 1986) and of the Kruger National Park (Trollope et al., 1990) in South Africa. This comprised determining the mortality of plants and, secondly, determining the total topkill of stems and branches of bush of different heights. The results indicated that bush is very resistant to fire alone and in the Eastern Cape the mortality of bush following a high intensity fire of 3875 kJ/s/m was only 9.3%.

In the Kruger National Park the average mortality of 14 of the most common bush species, subjected to 43 fires ranging in fire intensity from 110 to 6704 kJ/s/m, was only 1.3%. In both areas the majority of the trees that suffered a topkill of stems and branches coppiced from the collar region of the stem. Therefore it can be concluded that, generally, the main effect of fire on bush in the savanna areas is to cause a topkill of stems and branches forcing the plants to coppice from the collar region of the stem. The detailed results of this study are illustrated in Figure 4.1.

Figure 4.1. Effect of fire intensity on the topkill of bush, two metres high, in the Eastern Cape Province and Kruger National Park in South Africa.

4.2 a



4.2 b



The results in Figure 4.1 show that there was a significantly greater topkill of bush with increasing fire intensities. However, the research also showed that the bush became more resistant to fire as the height of the trees and shrubs increased, as is illustrated in Figure 4.2. This is clearly illustrated in the effects of low and high intensity fires on bush clumps of *Scutia myrtina* in the arid savannas of the Eastern Cape Province in South Africa (see Figure 4.2). The low intensity fire had a minimum effect on the topkill of the bushclump, whereas the high intensity fire caused a complete topkill of the stems and branches of the *S. myrtina* bushclump.

Similar responses were obtained in the arid savannas of the Eastern Cape Province in South Africa (Trollope & Tainton, 1986) as well as in the Scattered Tree Grassland: *Acacia-Themeda* savanna in the central highlands of Kenya (Trollope & Trollope, 1999).

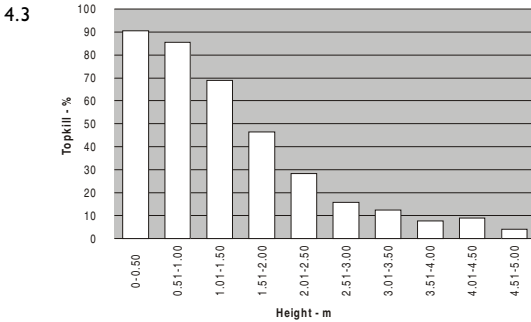
4.1.1.3 Season of Burning

The temporal and spatial distribution of savanna fires in Africa has been studied by Cahoon et al.

(1992) using night-time satellite imagery. The results indicate that most fires are left to burn uncontrolled so that there is no strong diurnal cycle in the fire frequency. The analysis of monthly satellite images for the period 1986 to 1987 indicates that January is the peak season for African savanna fires burning north of the equator, when all the savannas in these areas receive less than 25 mm of rain. These fires occur in a wide band stretching across the savannas south of the Sahara desert and the majority of them are initiated by human activities. Rainfall then increases in both hemispheres and savanna burning is reduced to a minimum during April. After April the rainfall decreases in the southern hemisphere and the frequency of savanna fires increases initially to a maximum during June in the western regions of southern Africa. From July to October savanna burning increases in the eastern portions and during the dry conditions prevailing during August and September fire activity reaches a maximum in East Africa and northern Mozambique.

An interesting difference in the season of burning exists between fires ignited by lightning and

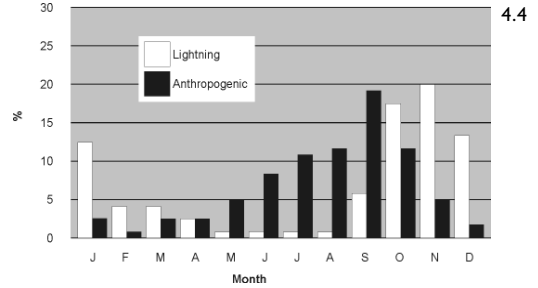
Figure 4.2 (a) and (b). The minimum and maximum effects of (a, left) low and (b, right) high-intensity surface head fires on the topkill of *Scutia myrtina* bushclumps in the arid savannas of the Eastern Cape Province in South Africa (Photos: W.S.W. Trollope).



anthropogenic sources. Studies in the Kruger National Park in South Africa, for the period 1980–1992, showed that lightning fires occurred most frequently during spring and summer (October to January) when thunderstorms are most frequent. Conversely, anthropogenic fires occurred mainly during the mid-winter to early spring period (June to September) (Trollope, 1993). These results are clearly illustrated in Figure 4.3.

Effect of season of burning on sward productivity

Season of burning is one of the most controversial questions concerning the use of fire in range management. Very little quantitative information is available on the effect of season of burning on the productivity of the grass sward. West (1965) stressed the importance of burning when the grass is dormant and advocated burning just prior to the spring rains at the end of winter in order to obtain a high-intensity fire necessary for controlling bush encroachment. Conversely, Scott (1971) stated that burning in winter damages the grass sward, and recommended burning after the first spring rains for all forms of controlled burning. However, more recent research has led to



the conclusion that for all practical purposes burning when the grass sward is dormant in late winter or immediately after the first spring rains has very little difference in effect on the grass sward (Tainton et al., 1977; Dillon, 1980; Trollope, 1987).

Effect of season of burning on species composition

Season of burning also has an effect on the botanical composition of the grass sward. It was found in the KwaZulu-Natal Province in South Africa that *Themeda triandra* declined after burning in autumn in comparison to burning in winter and spring, whereas *Tristachya leucothrix* responded in the exact opposite manner (Bond & Van Wilgen, 1996).

It is difficult to ascertain the effect of season of burning on woody vegetation because generally it is confounded with fire intensity. When the trees are dormant in winter the grass is dry and supports intense fires, whereas when the trees are actively growing during summer the grass is green and the fires are much cooler. West (1965) postulated that trees and shrubs are probably more susceptible to fire at the end of the dry season when the plant reserves are depleted due to the new spring

Figure 4.3. Effect of height on the topkill of bush subjected to a fire intensity of 3000 kJ/s/m, in the Kruger National Park, in South Africa.

Figure 4.4. The season of burning of lightning and anthropogenic ignited fires recorded in the Kruger National Park during the period 1980 to 1992.

growth. However, the results of Trollope et al. (1990) showed that the mortality of bush in the Kruger National Park was only 1.3% after fires that had been applied to bush ranging from dormant to actively growing plants. Therefore it would appear that bush is not sensitive to season of burn.

4.1.1.4 Frequency of Burning

The effect of frequency of burning on vegetation is influenced by *event-dependent* effects and *interval-dependent* effects (Bond & Van Wilgen, 1996). The *event dependent* effects occur at the time of the fire, and are influenced by the type and intensity of the burn and the physiological state of the vegetation at the time of the fire. The *interval dependent* effects are influenced by the treatment and growing conditions that occur during the interval between the burns. These two overall effects tend to confound the interpretation of the effect of frequency of burning and must be borne in mind when reporting on the effect of frequency of burning.

Effect of fire frequency on grass species composition

Frequency of burning has a marked effect on the botanical composition of the grass sward, with species like *Themeda triandra* being favoured by frequent burning, and *Tristachya leucothrix* being favoured by infrequent burning, in the moist grasslands of KwaZulu-Natal Province in South Africa (Scott, 1971; Dillon, 1980; Everson & Tainton, 1984). Similar results have been obtained in the arid savannas of the Eastern Cape in South Africa, where it was found that frequent burning favours an increase in *Themeda triandra* and a

decrease in *Cymbopogon plurinodis* (Robinson et al. 1979; Forbes & Trollope, 1990). In East Africa Pratt and Gwynne (1977) reported that *Themeda triandra* is a common constituent of grasslands in the Central Highlands of Kenya on undulating plateau and mountain flanks where fires are regular occurrences and the grazing pressure is not too high. Where fires are infrequent or lacking the upland grassland tends to become dominated by *Pennisetum schimperi* and *Eleusine jaegeri* which are coarse tufted species of very little value as grazing. These are *interval dependent* effects of frequency of burning, because *T. triandra* is sensitive to low light conditions that develop when the grass sward is not defoliated and this species rapidly becomes moribund during extended intervals between fires. Conversely, species like *T. leucothrix* and *C. plurinodis* are not as sensitive to low light conditions and survive extended periods of non-defoliation.

Effect of fire frequency on woody plants

Conflicting results have been obtained on the effect of frequency of burning on woody plants. Kennan (1971) in Zimbabwe and Van Wyk (1971) in the Kruger National Park in South Africa, both found that there were no biologically meaningful changes in bush density in response to different burning frequencies. In the False Thornveld of the Eastern Cape in South Africa, Trollope (1983) found that, after ten years of annual burning, the density of bush increased by 41%, the majority of which were in the form of short coppicing plants. Conversely, Sweet (1982) in Botswana and Boulton and Rodell (1981) in Zimbabwe found that annual burning resulted in a significantly

greater reduction in the density of bush than less frequent burning. It is difficult to draw any general conclusions from these contradictory results, except to note that in all cases significant numbers of trees and shrubs were present even in the areas burned annually, irrespective of whether they had decreased or increased after burning. These very variable results would also suggest that the effect of frequency of burning on woody vegetation is more an *event-dependent* effect where factors like the type and intensity of fire have had highly significant individual effects overshadowing the effect of frequency of burning *per se*.

On the contrary, the withdrawal of fire for extended periods of time appears to have a more predictable effect. For example, on the Accra Plains in south-eastern Ghana, protection of moist savanna from fire for 29 years has resulted in the development of a forest-type vegetation with a fairly closed canopy. The fire-sensitive tree species *Ceiba pentandra* became dominant (Carson & Abbiw, 1990). Similar results have been obtained in the Lamto Reserve in the Ivory Coast, which receives a high mean annual rainfall of 1300 mm and forms part of the Guinea savanna immediately adjacent to the deciduous rain forest. The savanna vegetation is subjected to annual burning during the middle of the dry season. In a study investigating the exclusion of fire for 13 years, it was found that after eight years the open savanna rapidly changes into a dense closed formation, and after 13 years the first signs of forest developing occurred in the form of seedlings and saplings.

This led to the conclusion that in all the burned savannas of Lamto the pressure of forest elements on savanna vegetation is very high and the exclusion

of fire initiates the development of forest (Menaut, 1977). Similar trends have been found in the more arid savannas (500–700 mm p.a.) in southern Africa, where in the Kruger National Park the exclusion of fire caused both an increase in the density and size of tree and shrub species (Van Wyk, 1971).

Effect of fire frequency on forage quality

The effect of frequency of burning on forage production has not been intensively studied in South Africa and only limited quantitative data is available. The general conclusion is that the immediate effect of burning on the grass sward is to significantly reduce the yield of grass during the first growing season after burning, but the depressive effect disappears during the second season (Tainton & Mentis, 1984; Trollope, 1983).

The effect of frequency of burning on the quality of forage is that generally frequent fires improve and maintain the nutritional quality of grassland, particularly in high rainfall areas, making it highly attractive to grazing animals. This phenomenon has been recorded throughout the savanna and grassland areas of Africa (West, 1965; Tainton et al., 1977; Moe et al., 1990; Munthali & Banda, 1992; Shackleton, 1992).

West (1965) stated that the fresh green shoots of new growth on burned grassland are very high in protein and quotes Plowes (1957), who found that the average crude protein content of 20 grasses after burning at the Matopos Research Station in Zimbabwe was 19%. This is approximately twice the protein content of mature grasses that have not been burned at the end of the dry season.

4.1.2 Fire Effects on Industrial Plantations

4.1.2.1 Fire Effects on Plantation

Floor Vegetation

It is only at the early stage of even-aged industrial plantations that the vegetation base relates mostly to its original, natural, source (grassland in the summer rainfall regions; fynbos in the Western and Southern Cape forest regions of Southern Africa). Once tree crown canopies are closed, and in consecutive rotations, the original vegetation may re-appear temporarily after clearfelling of the tree crop and timber exploitation, only to be suppressed again when the next tree rotation develops a closed crown canopy. After the young tree stage of the first tree rotation, when the crown canopy has closed, the forest floor consists mostly of leaf-fall components from the dominating commercial tree crop, as well as their seed store and seedlings. Often there is also an added “weed” component present, which may consist of species of previous planted commercial tree species such as *Acacia mearnsii* or *Eucalyptus* species, or other exotic invaders such as other *Acacia* spp., *Lantana* or *Setaria*, or indigenous species such as the fern *Gleichenia polypodioides* in forested regions of the Western Cape in South Africa. It is clear that these variations in the plant communities, during the different stages of the development of industrial plantations, will influence fire effects significantly, depending on the type of plant community that develops, together with the type and age of the tree crop and climatic conditions.

When a litter layer is the dominant cover of the soil surface underneath a continuous overstorey

in industrial plantations, most of the original green vegetation biomass, in the form of grasses and herbs, disappears. Some scattered shade-tolerant trees and shrubs may still be found inside mature stands, but otherwise the dominating overstorey will not permit the significant development of herbaceous vegetation. This also applies to any “weeds” that might have grown on these sites prior to having been planted with even-aged plantation trees, which have temporarily disappeared from these stands as a result of competition from the overstorey of the dominant trees. The effects of light intensity prescribed fires inside these stands are therefore minimal/nil.

The removal of overstorey trees inside industrial plantations (e.g. if trees are clearfelled) can have a drastic effect on exotic seed germination, particularly *Acacia* spp. such as *A. longifolia*, *A. mearnsii* and *A. melanoxylon*. This effect can even be more remarkable if slash is burned after timber exploitation. Likewise, removal of the plantation crown canopy by a high intensity fire – and subsequent exposure (or removal) of the protective forest floor layers such as duff – will expose the soil to higher air temperatures and increase fungal and other biotic activities (Davis, 1959). Where a lighter fire intensity only consumes a portion of the forest floor in mature plantation stands, seed stores will mainly remain unaffected by the fire temperatures, and regeneration will be significantly less, and normally patchy. It is clear that the effect of fire on the germination of seeds is also directly related to fire intensity, and the frequency of the fire. The hotter the fire, the more drastic will be this effect on forest floor vegetation regeneration (De Ronde, 1988). Other factors affecting the

response to fire intensity are the tree species itself and the moisture contents of the seedbed and seeds (e.g. Martin et al., 1975; Shea et al., 1979; Keeley, 1987; DeBano et al., 1988). Seed buried in the soil (such as *Acacia* seed stores) can also be insulated from the effects of fire and, therefore, not be affected by burning (DeBano et al., 1988). Seed can also be affected by the release from allelopathic inhibition, or the rupturing of a hard-seed coat (Gill, 1981).

Prescribed burning inside plantation stands can be used to stimulate germination of palatable grasses and herbs, and it can improve resprouting of shade-tolerant indigenous species such as *Laurophyllus capensis* (Vlok & De Ronde, 1989). Prescribed burning can also be used to eradicate weeds such as the Kyster Fern *Gleichenia polypodioides* in the Cape regions, and *Lantana* spp. in the summer rainfall areas (De Ronde, 1988). Normally there is a low frequency and cover of grass in mature industrial plantations, resulting in low grazing capacity for domestic livestock and wild ungulates. However, grazing livestock, herbivores and other wildlife populations, often benefit from post-fire changes in forage biomass and quality, after prescribed burning inside stands, and slash burning after clearfelling and timber exploitation. Crude protein content is often higher in forage plants than in plants growing on unburned sites, at least in the first post-fire growing season (DeBano et al., 1988). In South Africa, significant increases in cover and frequency of grass species, such as *Ehrharta* spp., have been recorded. Such increases in the grass sward makes industrial plantations attractive to grazing animals (De Ronde, 1988).



4.5

In certain areas the bracken fern (*Pteridium aquilinum*) forms an important component of the herbaceous layer in industrial plantations. Under these conditions it does not increase in abundance after burning, whereas it increases significantly after clearfelling and slash burning. Bracken fern is apparently more influenced by the degree of crown canopy cover of the dominant tree species and the type of season (e.g. germinating better during the wet season), than by fire (Van Loon & Love, 1971; De Ronde, 1988).

Application of a low intensity fire under a dominating overstorey can also facilitate micro-climatic changes in decomposition dynamics, and thus indirectly contribute to improved forest floor vegetation regeneration of both the natural and exotic components. In stands with a poor litter breakdown as a result of lack of fungal activities within forest floor layers, litter loading may accumulate, and even a low intensity fire can increase pH and nutrient availability significantly. This will encourage increased fungal activities and improve litter decomposition and can also lead to increased regeneration and stimulation of natural beneficial and exotic detrimental seed stores (De Ronde, 1992).

Figure 4.5. An example of dominance of *Ehrharta* spp., after a single low intensity prescribed burn has been applied in a mature *Pinus pinaster* stand (Photo: C. de Ronde).

4.1.2.2 Fire Effects on Fungi and

Soil Micro-organisms

Complex interrelationships exist between soil heating and the survival of bacteria and fungi. Duration of heating, maximum temperatures and soil water content are the most important factors affecting the response of microbes and other biological organisms to soil heating (Dunn & DeBano, 1977). Some litter accumulation problems have been recorded in Pine plantations in southern Africa, as a result of (either) a lack of fungal activity or of the absence of key soil micro-organisms responsible for humus (duff) breakdown (De Ronde, 1984; De Ronde, 1992; Morris, 1986; Schutz et al., 1983).

In the Cape Forest regions of South Africa humus (or duff) layers fail to be incorporated as organic matter in the soil because of the apparent lack of capabilities of fungi and soil micro-organisms to fulfil this task on clayey, duplex soils. In *Pinus elliottii* stands of the Tsitsikamma region in South Africa, the abundance of fungi decreased significantly with an increase of humus thickness, indicating that a lack of fungal activity is one of the causes of humus accumulation (De Ronde, 1992). As the problem is particularly related to low soil acidity, it is possible that prescribed fire (and subsequent pH increases) can improve decomposition on these soils, although this aspect has not been properly researched to date (De Ronde, 1992).

At high altitude in the summer rainfall regions of South Africa and Swaziland, lack of fungal activity is apparently sometimes responsible for a total absence of fermented layer breakdown into humus, causing needle layers to accumulate to levels

exceeding 700 metric tons per ha (Morris, 1986; Schutz et al., 1983).

Again, low acidity (but also some poor nutrient levels), appears to be responsible for the almost total absence of fungi, and liming has produced a significant improvement (Morris, 1986). Prescribed fire can be used to reduce litter-loading levels first, which can then provide a better microclimate for fungal activity in forest floor layers by increasing pH and nutrient availability (De Ronde, 1992). However, further longer-term studies are required to understand and quantify these effects.

4.1.2.3 Fire Effects on Trees

Types of tree damage

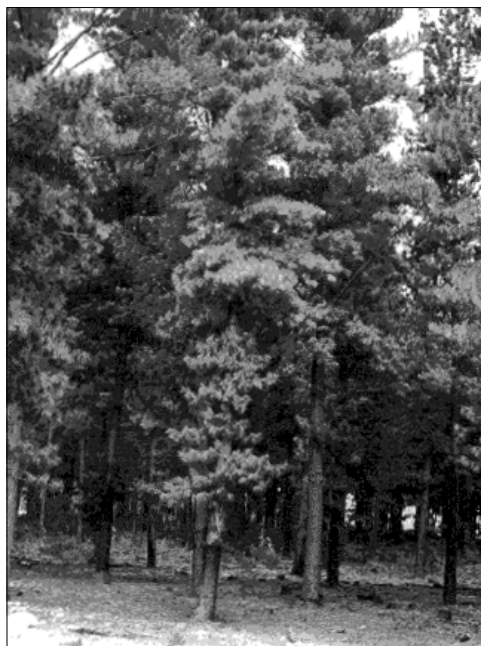
Fire damage to trees depends upon the susceptibility of different species to fire, age of the trees and fire intensity. The following types of fire damage can occur:

Cambium damage

Chandler et al. (1983) have listed the characteristics of bark, which are important in insulating the cambium layers, as follows:

- Bark thickness
- Density of bark
- Thermal conductivity
(rate of penetration of temperature)
- Moisture content
- Bark thermal absorptivity
(the capacity of the bark to absorb heat rather than to transfer it to cambium layers)
- Combustion properties

4.6



Injury to tree cambium normally occurs on the leeward side of trees (i.e. the opposite side of the tree stem relative to the advancing fire front) just above ground level. This phenomena is not only experienced because it occurs closest to the mid-flame height, and thus where the highest fire temperatures are found in the vertical profile, but also because – as the wind blows a fire past the tree – the flames are drawn into the eddy zone on the leeward side, and will then extend further up on that tree (Cheney & Sullivan, 1997).

Crown scorch

In most cases tree mortality is generally related to crown damage rather than to bole damage (Cooper & Altobellis, 1969; De Ronde, 1983; Kayll, 1963; Wade & Ward, 1975). The susceptibility of

certain species to crown scorch may differ within a genus, e.g. the needles of some *Pinus* species (such as *Pinus patula* and *Pinus radiata*) are more susceptible to crown scorch by a given fire temperature than other species such as *Pinus elliottii*.

Crown scorch can be described as the mortality of leaves caused by a surface fire, which is then displayed in the form of crown discolouration, without leave consumption. This discolouration will be visible immediately after the fire, and leaves will drop from the trees some weeks later.

Crown fire

This occurs when a surface fire is carried into the crowns of trees, resulting in the complete combustion of the leaves (De Ronde, 1990). The effect of total crown consumption is drastic and recovery is rare, although scattered recovery of some trees has been observed after resprouting has occurred in the crowns of some trees (De Ronde, 2001). *Pinus* trees exposed to crown fires will experience high mortality, and standing timber will dry and degrade rapidly (De Ronde et al., 1986).

Root damage

Roots have a thin cortical covering and, if found near the soil surface, are easily damaged by fire. Shallow rooted species are frequently damaged by ground fires as a result of injury to roots, even though the stem and crown are not affected (Davis, 1959; De Ronde et al., 1986). The depth and character of the forest floor (organic layer) may largely control damage inflicted by surface fires to roots, especially of the more shallow-rooted trees (Davis, 1959).

Figure 4.6. Example of crown scorch in *Pinus radiata* (Photo: C. de Ronde).

Secondary damage

Where damage in the form of severe crown scorch and/or cambium damage has occurred to trees, some resprouting after a fire may give the impression that the trees are recovering. However, within months, the new leaf development can die back and mortality occurs (De Ronde, 1983). In the case of *Pinus* tree species, the cause of this mortality may be due to the pathogen *Rhizina undulata*, which attacks the remaining living roots where the cambium was not damaged. This type of secondary damage is particularly common where the humus has been consumed by fire (Baylis et al., 1986). The bark beetle *Ips erosus* may also cause mortality where trees have been severely injured by fire (Baylis et al., 1986).

Crown damage versus crown scorch

Scorched leaves and needles may remain on the trees for up to two months after a fire with common crown scorch, but they are completely consumed when crown fires occur (De Ronde et al., 1986). The effect of leaf or needle consumption is drastic, and recovery is rare where crown fires have occurred. In most stands, total mortality results when stands have been exposed to crown fires.

In the case of crown scorch, needles or leaves are not consumed, and particularly if crowns are not completely damaged, tree survival often occurs. Even total crown scorch may result in tree survival, as some tree species are able to resprout (e.g. *Pinus elliotii*). However, some trees may show an initial “flush” of new growth, but can then die back within months as a result of secondary damage (De Ronde et al., 1986).

Healthy *Pinus elliotii* trees up to five years old, may recover completely after wildfires caused total crown scorch, even when growth leaders died or were damaged (Wade & Ward, 1975).

Cambium damage versus crown damage

Researchers have observed that generally tree mortality is related to crown damage rather than to bole damage (Cooper & Altobellis, 1969; Crow & Shilling, 1978; De Ronde, 1983). If species such as *Pinus patula* or *Pinus radiata* experience less than 25% crown scorch, widespread cambium damage may still result in degradation, loss of growth or even mortality. It is also evident that the thin crown needles of these species are more susceptible to crown scorch for a given fire temperature than needles from other species, such as *Pinus elliotii*, *Pinus taeda* or *Pinus pinaster*. The latter species are also more resistant to cambium damage. However, age is also important, as bark thickness increases with age and therefore resistance to cambium damage will increase (De Ronde, 1982). It is therefore important to consider cambium damage as a degrading factor, where age and/or natural resistance of bark layers are low (Davis, 1959; Van Loon & Love, 1971; De Ronde, 1982).

Fire damage assessment

In this section we will discuss the role of fire effect evaluation, in the form of fire damage assessment, in even-aged industrial timber plantations. It is important that the damage to trees (timber crop) and soil (tree growth media) is assessed within weeks after a wildfire, and that the status of degrade or recovery is monitored regularly

thereafter. After each wildfire, the impact of the fire should be classified as follows:

Light impact

It is mostly crown scorch that is experienced in this class, and crown fire consumption is rare or absent. A partly consumed forest floor is another characteristic of this damage class, and there is normally no direct exposure of soil surfaces to hot fire temperatures, with no yellow or white soil surface discolouration. Erosion potential is also rare in this class.

Medium impact

Both crown fire consumption and various degrees of crown scorch have occurred and most of the forest floor biomass has been consumed by fire. Soil surface exposure to hot fire temperatures may be more common than in the case of a light impact fire, but is still only found in less than 25% of the area affected by the wildfire. Erosion damage may occur on steep slopes.

Serious impact

Crown fire consumption by crown fires and so-called "crown fire streets" (black crown fire lines pointing in the direction of maximum fire spread) are common. Where crown scorch occurs, this will dominantly be in the form of complete scorch of crown volumes. All forest floor material was consumed by fire, and exposure to hot fire temperatures has resulted in common soil surface discolouring and water repellency. Serious soil erosion damage will be experienced on most terrain affected by the fire, and will not be restricted to steep slopes.

Assessment of damage to trees

Individual trees and tree stands can be assessed for fire damage as follows:

- *Inspecting for cambium damage*

Injuries to the cambium and phloem are not easy to detect by external inspection, and the need for a rapid non-destructive method for detecting the presence of dead cells within the cambium and phloem tissue, has been identified as early as during the 1960's (Curtin, 1966). Once cambium damage is suspected, it can be detected by inspecting the bark just above the ground line, on the leeward side of trees (Fahnestock & Hare, 1964). Cambium damage can be identified by discolouration (Cremer, 1962), by the use of stains such as tetrazolium chloride (1% solution in water) (Kayll, 1963), tissue fluorescence, cytoplasmic steaming, enzyme activity and gas exchange (Curtin, 1966). Of these methods, the tetrazolium test is probably the simplest, apart from direct field inspection of the tissue for discolouration (De Ronde et al., 1986). This is done by placing cambium tissue in a test tube filled with a 1% tetrazolium mixture in water, and discolouration of the cambium into a pinkish colour will tell you that the tissue is alive. No colour change means the tissue is dead (De Ronde, 1982).

- *Marking and mapping affected crown fire damage areas*

As the crown needles of trees exposed to crown fires have been completely consumed by the fire, almost all trees falling in this category

will die, and degrading of timber will be relatively fast in these areas compared to trees that experienced only crown scorch. It is important to mark these areas clearly in the field with paint spots on tree stems, and to map crown fire areas where they commonly occur, as these trees will have to be exploited soon after the fire.

- *Classifying and monitoring degree of crown scorch*

It is important to divide this type of fire damage in two categories, namely (a) total crown scorch and (b) partial crown scorch. In the case of the latter, most trees normally survive, unless they have been exposed to secondary damage. In the case of total crown scorch, trees such as *Pinus radiata*, *Pinus patula* and *Acacia* spp. will probably die (apart from stump resprouting in the case of the latter), while species such as *Pinus elliottii*, *Pinus taeda* and *Eucalyptus* can sometimes resprout readily during certain seasons (De Ronde et al., 1986). Monitoring of the tree status over time is thus important.

- *Inspecting for root damage*

Where shallow root systems occur, exposed roots must be inspected for damage, as secondary damage may occur at a later stage caused by e.g. *Rhizina undulata* (De Ronde et al., 1986).

- *Regular inspection for Rhizina undulata fruiting bodies*

In cases where the soil surface was completely exposed to fire, *Rhizina undulata* damage is

possible, and stands should be inspected within weeks after a wildfire has occurred in *Pinus* plantations, and at monthly intervals thereafter. Where a needle mat was formed from fallen (scorched) pine needles, these continuous layers should be lifted up to inspect the soil surface underneath it for fruiting bodies formed by this pathogen. Old tree stump channels should also be inspected for signs of *Rhizina* on the channel sides underneath the soil surface.

Rhizina may also attack damaged trees so that they die back steadily, and this can be observed by inspecting surviving tree crown needles for signs of dying-back and yellowing. This kind of damage may only be noticed months after the fire, but can be very serious and common. Re-establishment of the trees should then also be postponed until the *Rhizina* fruiting bodies have dried out (Linguist, 1984; De Ronde et al., 1986). The pathogen may also appear in areas where slash was burned, in which case re-establishment will have to be postponed for a few months until it has been observed that the fruiting bodies are dying-back.

- *Inspection for Ips erosus and Cerambycid beetles*

These may or may not play a significant role in tree mortality, and inspection of tree stems for any presence of these tree borers is recommended. If observed, further studies and expert advice may be required, and the assistance of plant protection experts may have to be requested (Baylis et al., 1986).

Assessment of erosion potential

Classifying the impact of a wildfire, as explained earlier in this section, will provide managers with a useful indication of soil erosion potential. Erosion should also be considered in relation to actual topographical features of the area that were exposed to the wildfire. If a “serious impact” has been identified on steep terrain, even mild rain showers may result in serious soil erosion, while in the case of “medium impact”, only heavy rain showers may result in serious erosion problems.

“Sheet erosion” – where sheets of soil surfaces from higher ground are coming loose from higher lying ground to be dumped into valleys – will only occur where excessive rainfall is experienced on very steep slopes.

Certain soil or land types may also be more susceptible to soil erosion than others. Where this potential exists, it may assist managers to test for water repellency (where there is a resistance of water penetration into the soil profile). These tests can be applied by simply pouring water drops on soil surface slopes. If the water penetrates the soil, there is no water repellency problem, but where these water drops fail to penetrate the soil surface, and the drops roll down the slope without penetrating it, a water penetration resistance exists.

Assessing tree re-establishment potential

The more serious the wildfire impact, the more problems can be expected with tree replanting. In the case of a wildfire that occurred on a nutrient-poor site, steps will have to be taken to overcome nutrient deficiencies, and soil sampling to determine the nutrient status of the topsoil (a

few months after the wildfire) is recommended. After serious impact fires, more problems can also be expected as a result of physical damage to soil properties, and these sites are also more susceptible to *Rhizina undulata* infestation.

Exploitation scheduling after wildfire damage in industrial plantations

Apart from the assessing and monitoring procedures that are recommended, there are a few important rules that must be considered when exploitation of timber is scheduled and prioritised. They are:

- Standing timber does not degrade as fast as felled timber; thus timber should not be felled too long ahead of timber transportation.
- To ensure that there is always a sufficient timber volume available for transport, attempts should be made to have approximately two days’ of timber transport volume on roadside. Less volume may result in a delay of supplies while more volume may cause an unnecessary high rate of timber degrade.
- Regular adjustments of exploitation schedules are necessary where either (a) the degree of mortality is significantly improved by “better-than-expected” tree recovery or (b) secondary damage is degrading more timber volumes that were originally classified under the “possible survival” class.
- Where “faster-than-expected” blueing of timber is taking place as a result of factors such as (a) adverse weather conditions (e.g. high humidity), (b) hail damage after the wildfire, that has damaged trees further, or (c)

continued drought stress for a prolonged period after the wildfire occurred.

- The rate of timber degrade (in particular the blueing of timber) can be significantly delayed by putting felled timber logs under water sprinkler systems, or by putting some timber log volumes under water surfaces, such as in dams. The latter, however, has the disadvantage that the recovering of the timber from the water may be a time-consuming operation. These methods of delaying timber degrade are only recommended for timber volumes that exceed the volume that can be

recovered (at best) by timber intake resources, and with timber that would otherwise be lost.

The recommended assessment programme for *Pinus* plantations that were exposed to wildfire is outlined in Table 4.2.

Checking and monitoring procedures for damage in *Eucalyptus* or *Acacia* stands depend on whether the timber of these damaged trees can be utilised at all. If this timber is recoverable, the same basic rules apply as for *Pinus* spp.

Table 4.2. Recommended assessment procedures in even-aged *Pinus* plantations.

Time after fire	Young trees before crown canopy closure	Stands with partly-closed crown canopy	Stands with closed crown canopy < 18 years old	Stands with closed crown canopy > 17 years old
3–4 weeks after the wildfire	Crown and cambium damage assessment (all spp.)	Crown and cambium damage assessment (all spp.), cambium damage assessment (<i>P.patula</i> , <i>P.radiata</i>)	Crown assessment (all spp.) cambium	Crown damage assessment (all spp.)
Weekly (starting 5 weeks after, and ending 9 weeks after the fire)	Only <i>P. ell.</i> for re-sprouting, recovering potential. Other spp. will fall in mortality class.	All spp.: Check crowns for resprouting or dying-back	All spp.: Check crowns for resprouting or dying-back	Only check <i>P. patula</i> , <i>P. radiata</i> crowns for resprouting or dying-back
Monthly (after the 9 weeks period after the fire)	None (trees already either felled or recovered)	None (trees already either felled or recovered)	All spp.: Check crowns for resprouting or dying-back, and forest floor for <i>Rhizina</i>	All spp.: Check crowns for resprouting or dying-back, and forest floor for <i>Rhizina</i>

4.1.3 Fire Effects in Natural, Indigenous Forests

Wildfire is a rare occurrence in indigenous forests and is not often experienced on a large scale (normally only after long periods of extreme droughts). In most cases, however, forest edges can be exposed and damaged by fires occurring in adjoining biomes or plantations. A relatively shade-tolerant, dominant, understorey of herbaceous grasses and herbs may occur in these forests, with typical species such as *Oplismenus hirtellus*. Significant fire effects on these communities are rare, and are normally restricted to small, disturbed forest patches. The shade-tolerant forest floor vegetation and understorey, found under the overstorey canopy of these forests, provide a better maintained micro-climate with a high moisture retention, which is ideally suited for protection against external fire damage threats. Better decomposition dynamics in these evergreen forests also provide less prominent forest floor layers, as sometimes found in mature industrial plantation stands (De Ronde, 1988).

Where industrial plantation stands have to be converted back to natural indigenous forests, it is important that slash is not burned after clear-felling the plantation trees. Burning of slash puts the recovery process back much further, and it may stimulate the regeneration of unwanted herbaceous vegetation and weedy woody plants, such as *Acacia mearnsii*. Even at the Diepwalle Arboretum in the Knysna forests in South Africa, where at the time of establishment (1932) the

one part was cleared and the slash burned, and another part left intact before planting the pure stands of different indigenous species, the composition and understorey of tree regeneration of these planted stands were varied during sampling in 1990 (Lübbe & Geldenhuys, 1991). With regard to the Bracken fern *Pteridium aquilinum* in indigenous forests, it will not re-establish in a forest opening unless the area was burned, such as when a lightning strike has occurred or where there is a fire "gap".

Fires in the forest environment cause the establishment of typical layer communities. On the forest margin and even inside the forest, with large gaps or parts of the forest destroyed, pure stands of the legume tree *Virgilia divaricata* develop. They gradually nurse the establishment of more shade-tolerant forest species, and eventually the pioneer stand disappears, leaving a soil-stored seed bank (Geldenhuys, 1994).

After a lightning fire, or spot fires started by wind-carried burning plant parts, small burnt spots are covered by different fern species, such as *Pteridium aquilinum* if the gap is relatively large, or *Hypolepis sparsisora* (Geldenhuys et al., 1994). The presence of extensive layers of the fern *Rumohra adiantiformis* indicates areas where fire had been burning inside the forest in the past (Geldenhuys, 1993).

In mountain forests in the Southern Cape, South Africa, dense stands of the fern *Blechnum tabulare* indicate the areas where fires from the outside regularly burn into the forest understorey (Geldenhuys, 1993).

4.2 FIRE EFFECTS ON FAUNA

4.2.1 Introduction

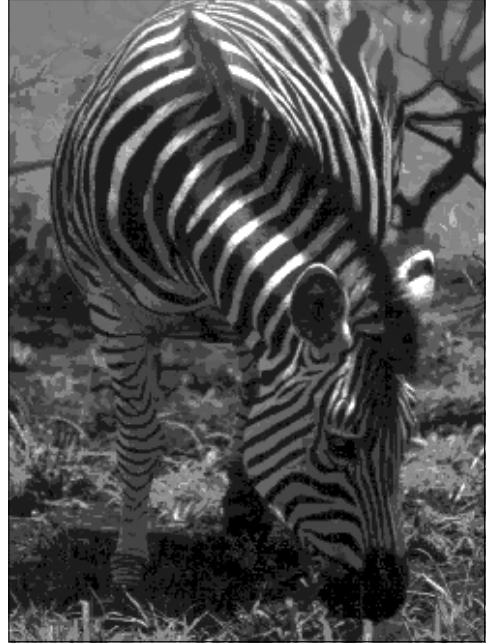
Fire affects both the abiotic and biotic components of a system (Scholes & Walker, 1993). Although the primary impact of fire is on vegetation, it is also important to consider the effect fires have on fauna, most especially in protected areas where the aim is the conservation of biodiversity. Since fire has occurred in sub-Saharan Africa for thousands of years, fauna in fire-prone areas are well adapted to it, and have consequently developed a range of responses to fire (Frost, 1984). These include avoidance of fire, active use of the fire and burnt areas for feeding, or as cues for breeding (e.g. birds). Fire acts on fauna exerting both direct and indirect effects.

4.2.1.1 Direct Effects of Fire on Fauna

Mortality, a major direct effect of fire, is generally low because most animals move out of the affected area. Mortality is likely to be higher in flightless arthropods, and also insects in vulnerable stages of development (e.g. larval stages). Dispersal is often an immediate reaction to fire, and it is an important cause of faunal change.

4.2.1.2 Indirect Effects of Fire on Fauna

Indirect effects of fire are related to the alteration of the physical environment, fire impacts on vegetation structure and composition. This can lead to changes in food quantity and quality, cover, and micro-site characteristics (e.g. soil moisture, ground temperature). These environmental changes then affect faunal populations. Another indirect effect of the fire is that some species



4.7

may utilise the burned open areas to reduce predation risk since visibility is improved. Conversely, other species may become more vulnerable to predation. These effects of fire on different taxa can vary, as will be discussed later in this section. However, it is clear from the literature that there are many deficiencies in our understanding. Available data, often unpublished, are concentrated in certain biomes or on certain taxa (Parr & Brockett, 1999). To date there is no recent synthesis on the effects of fire on fauna (see Bigalke and Willan [1984] and Frost [1984] for the latest reviews). For these reasons it is difficult to generalise, and thus discussion is often limited to a few studies and qualitative personal observations.

Figure 4.7. Zebra grazing on re-growth after fire (Photo: C.L. Parr).

4.2.2 Large Mammals

It is a useful simplification to consider herbivores as either food *quantity* or food *quality* limited. Food quality refers to the nutrient content of the forage, and principally to its nitrogen (protein) content. Herbaceous layer primary productivity in the first growing season post-fire is enhanced due to the removal of moribund material and the stimulus given to the growth of young tillers that keeps the grass layer in a more productive and palatable growth phase (Tainton et al., 1977). Grass growing immediately after a fire contains an above average content of nitrogen (considered a critical limiting factor for herbivores) (Tainton et al., 1977; Van der Vijver, 1999). Post-fire tillers are higher in nitrogen (protein), and are more digestible (having less structural carbohydrates or fibre) than unburned vegetation. For these reasons, post-fire regrowth is more attractive to grazers (Van der Vijver, 1999).

Changes in food quality may then lead to changes in population sizes and composition, and the temporal redistribution of animals, as they move away from the burned areas, or are strongly attracted to them (Moe et al., 1990; Wilsey, 1996). Such changes in animal distribution and density may be immediate or occur over a few days, weeks or months. Furthermore, this movement of animals onto burned or unburned areas is also a function of a number of other factors such as type of habitat burned as well as the surroundings, season and size of fire. Moist-fertile savannas and grasslands are food quality limited, and hence burning in these areas has strong effects on herbivore use. As a consequence, herbivores exhibit a range of responses, in time, to fire. Essentially,

species can be grouped into the following classes, which represent a post-fire grazing-recolonisation succession:

- Species that exploit the immediate post-fire conditions, e.g. warthog (*Phacochoerus aethiopicus*) and zebra (*Equus burchelli*).

Zebra remove green shoots that are sometimes available immediately post-fire (following the removal of moribund herbage), and they later return once sufficient regrowth has occurred (Parr and Brockett, pers obs; Figure 4.6, Table 4.3). Warthog make use of the exposed roots and tubers post-fire.

In the Hluhluwe-Umfolozi Game Reserve, South Africa, feeding surveys of black rhino (*Diceros bicornis*) were carried out. It was found that feeding levels were significantly higher in burned versus unburned plots; the black rhino favouring recently-burned twigs. Fires of low to moderate severity were more beneficial to black rhinos than hot fires because hot fires removed more of the aboveground (scrub) biomass. Burned Acacias were particularly favoured (e.g. *Acacia karroo*, *A. nilotica*, *A. tortilis*, *A. caffra*, *A. gerrardii*, *A. senegal*, *A. borleae* and *Dichrostachys cinerea*). In high rainfall areas, burning is advantageous to black rhino as it removes tall grass that would otherwise interfere with browsing (Emslie & Adcock, 1994).

- Species that utilise the post-fire regrowth, e.g., blesbok (*Damaliscus dorcas phillipsi*), impala (*Aepyceros melampus*), zebra, white rhino (*Ceratotherium simum*) and springbok (*Antidorcas marsupialis*), Grant's gazelle

(*Gazella granti*), Thompson's gazelle (*Gazella thompsoni*) as well as black wildebeest (*Connochaetes gnou*) (Brooks & Berry, 1980; Gandar, 1982; Moe et al., 1990; Wilsey, 1996).

At the Nylsvley Nature Reserve, South Africa, impala were found to increase in numbers on burned areas from day ten after a fire, until day 30. Typically they prefer fine-leaved woodland, but after a fire in broad-leaved wooded areas, they move into this woodland type (Gandar, 1982). Novellie (1978) recorded springbok and blesbok feeding on recent burns at the highveld of South Africa, and also mountain zebra on burned areas in the Mountain Zebra National Park (Novellie, 1990). On recently burned areas, blesbok are relatively unselective feeders, but if grazing on unburned vegetation, they tend to become selective for certain grass species (Du Plessis, 1972), and therefore one objective of burning in wildlife areas would be to reduce selective grazing.

In the Serengeti, Tanzania, it was found that preference for burned areas was negatively related to average ungulate body size across species. It is hypothesised that larger species feed on both burned areas where there is a low quantity of high quality forage, and unburned sites where forage quantity is high but quality is low, in an effort to maximise their energy and nutrient intake. Smaller sized species are better able to feed exclusively on burnt areas with high quality forage to fulfil high metabolic requirements (Wilsey, 1996). This is illustrated by white rhinos strongly selecting for burnt areas for high quality forage, and also utilising older (unburnt) areas for herbage intake.

- Species that use the habitat after sufficient re-growth has occurred, e.g. oribi (*Ourebia ourebi*), mountain reedbuck (*Redunca falvorufula*), sable (*Hippotragus niger*) and roan (*Hippotragus equinus*).

In the KwaZulu-Natal Drakensberg, South Africa, grey rhebuck (*Pelea capreolus*), mountain reedbuck, oribi and blesbok were observed feeding on veld less than one year old, and in recently burned fire breaks in preference over one- to two-year-old grassland. Despite this obvious preference for recently burned areas, there remains a need for unburned patches in the landscape because they provide cover, which is important to grey rhebuck, mountain reedbuck, oribi and sable, as lying-out behaviour is practised by all of these antelope for at least six weeks after the young are born (Oliver et al., 1978; Rowe-Rowe, 1982; Everett et al., 1991; Estes, 1991). Shackleton and Walker (1984) stress that in the absence of burned areas the forage preferred by oribi is very limited. Change from predominantly autumn to spring burns resulted in a decline in antelope numbers in Giants Castle Reserve, KwaZulu-Natal (Bigalke & Willan, 1984), and Mentis (1978) suggested that nutrition was limiting populations of grey rhebuck, and oribi in the KwaZulu-Natal Drakensberg, and it was found that autumn burns in particular appear to support higher oribi densities (Everett et al., 1991). Autumn burns help to reduce nutritional stress and antelope mortality in the winter months because the re-growth has higher crude protein content and phosphorous levels than would otherwise be present. In Pilanesberg National Park, South Africa, sable antelope were also found to

Table 4.3. Summary of large mammal species utilisation of burnt areas.

Species	▼ A	● B	■ C	References
Black rhino (<i>Diceros bicornis</i>)	▼			Emslie & Adcock (1994)
Black wildebeest (<i>Connochaetes gnou</i>)		●	■	Brooks & Berry (1980), Gandar (1982), Wilsey (1996)
Blesbuck (<i>Damaliscus dorcas phillipsi</i>)		●		Du Plessis (1972), Novellie (1978), Brooks & Berry (1980)
Blue wildebeest (<i>Connochaetes taurinus</i>)		●		Moe et al. (1990), Wilsey (1996)
Grant's gazelle (<i>Gazella granti</i>)		●		Wilsey (1996)
Grey rhebuck (<i>Pelea capreolus</i>)		●	■	Oliver et al. (1978), Rowe-Rowe (1982)
Gemsbuck (<i>Oryx gazella</i>)		●		Brockett (pers. obs.)
Impala (<i>Aepyceros melampus</i>)		●		Brooks & Berry (1980), Gandar (1982), Moe et al. (1990), Wilsey (1996)
Mountain reedbuck (<i>Redunca falvorufula</i>)		●	■	Olivier et al. (1978)
Oribi (<i>Ourebia ourebi</i>)		●	■	Everett et al. (1991), and Brockett (pers. obs.)
Roan (<i>Hippotragus equinus</i>)		●	■	Dörgeleh (1998), Gujera & Owen-Smith (2002)
Red hartebeest (<i>Alcelaphus buselaphus</i>)		●		Gureja & Owen-Smith (2002), Brockett (pers. obs.)
Sable (<i>Hippotragus niger</i>)			■	Grobler (1981), Magome (1991), Gujera & Owen-Smith (2002)
Springbuck (<i>Antidorcas marsupialis</i>)		●		Novellie (1978), Brooks & Berry (1980)
Thompson's gazelle (<i>Gazella thompsoni</i>)		●		Wilsey (1996)
Tsessebe (<i>Damaliscus lunatus</i>)		●		Gureja & Owen-Smith (2002), Brockett (pers. obs.)
Warthog (<i>Phacochoerus aethiopicus</i>)	▼			Parr & Brockett (pers. obs.)
White rhino (<i>Ceratotherium simum</i>)		●	■	Brooks & Berry (1980), Brockett (pers. obs.)
Burchell's Zebra (<i>Equus burchelli</i>)	▼	●	■	Wilsey (1996), Gureja & Owen-Smith (2002), Parr & Brockett (pers. obs.)
Mountain Zebra (<i>Equus zebra</i>)	▼	●		Novellie (1990)

- ▼ Species that exploit immediate post-fire conditions
- Species that utilise post-fire regrowth
- Species that require sufficient post-fire regrowth

utilise autumn and early winter burns (Magome, 1991). Autumn burning increased population size, and is therefore recommended for sable production. Roan antelope have been reported to be highly selective of burned areas (less than six months old) in the Nyilsvey Reserve (Dörgeleh, 1998).

- Browsers and mixed feeders may avoid burnt areas, especially following dry-season fires, e.g. eland (*Taurotragus oryx*), kudu and elephant (Frost & Robertson, 1985).

Often only when sufficient browse regrowth has occurred do species such as kudu (*Tragelaphus strepsiceros*) return to burned areas. Bell and Jachmann (1984) found that elephants (*Loxodonta africana*) in *Brachystegia* woodland tend to avoid areas burned in the early dry season. Similarly, in the Luangwa Valley, Zambia, it was found that following early dry season fires, elephant browse intake was reduced. Consequently forage utilisation in surrounding unburnt areas increased (Lewis, 1987).

4.2.3 Small Mammals

Species that occupy burrows, such as the pygmy mouse (*Mus minutoides*), the multimammate mouse (*Mastomys natalensis*) and the forest shrew (*Myosorex varius*), appear better able to survive both fires and the subsequent intensified predation and increased exposure before vegetation cover is restored (Meester et al., 1979). In the KwaZulu-Natal Drakensberg, it was found that burning decreased the abundance of small mammals with usually only one species, the insectivorous *M. varius*, being present. As grass cover

increased, more species re-colonised the area. Long periods without burning were found to result in a decrease in the number of species (Rowe-Rowe & Lowry, 1982). These results concur with a study in Zimbabwe, which found that small rodents were more abundant in the unburned area than the burned area for four months after the fire (Swanepoel, 1981). A study in the Kruger National Park, South Africa, revealed intra-habitat and inter-habitat differences in small mammal community responses to fires, differences relating to burning frequency. In *Terminalia-Dichrostachys* habitat (in the Pretoriusskop area), annual burning decreased species diversity and promoted dominance by one species, while no burning was found to maintain high species diversity. Conversely, in the *Acacia-Sclerocarya* habitat (in the Satara area), annual burning was found to result in high species diversity, and no burning maintained high population densities of two species (Kern, 1981).

The problem with many of the above conclusions is that the results are often a function of the burned/unburned vegetation mosaic. In addition, many of the studies have low catch success rates, and consequently conclusions are being drawn with little data.

4.2.4 Birds

Often the immediate impact of fire for many species of birds is the provision of food either during the fire or immediately afterwards in the way of dead insects. Birds have been frequently reported as flocking to fires during the day when they can feed on insects moving ahead of the fire front (e.g. Dean, 1987; Parr, pers. obs.), and many

birds are also attracted to recently burned areas, particularly insectivorous species due to the high mortality of insects. Fork-tailed drongos (*Dicrurus adsimilis*) and lilac-breasted rollers (*Coracias caudate*) forage on insects escaping fire, and gregarious species such as cattle egrets (*Bubulcus ibis*) forage immediately behind fire fronts and on recently burned areas, as do white storks (*Ciconia ciconia*) (Brockett, pers. obs.). In the case of the white storks, these are usually non-breeding birds. The grey hornbill (*Tockus nasutus*) exploits burns by feeding on grasshoppers on burnt ground for a couple of weeks after a fire (Gandar, 1982), and bald ibis (*Geronticus calvus*) too feed on recently burned ground (Manry, 1982).

In addition to feeding, certain species of bird use the recently burned ground for breeding. These species include the blackwinged plover (*Vanellus melanopterus*), bronze-winged courser (*Rhinoptilus chalcopterus*), Temminck's courser (*Cursorius temminckii*), pennantwinged nightjar (*Macrodipteryx vexillaria*) and the dusky lark (*Pinarocorys nigrescens*) (Dean, 1974; cited in Frost, 1984). These species exhibit a number of adaptations for nesting on burned ground. In *Vanellus* spp., *Rhinoptilus* spp. and *Cursorius* spp., for example, eggs are dark-coloured, and chicks have heavily pigmented down (Frost, 1984). Burned areas may be favoured as nesting grounds as they allow for better predator detection and higher food levels for insectivorous birds. For other ground-nesting species, however, fire could potentially result in the removal of habitat cover, and if at other times of year, the destruction of nesting grounds.

Francolins in the highland grassland areas of South Africa have been studied intensively.

Redwing francolin (*Francolinus levallantii*), are much less tolerant of high frequency burning than grey-wing francolin (*Francolinus africanus*), and as a consequence are mainly confined to unburned, ungrazed grasslands (Mentis & Bigalke, 1979; Jansen et al., 1999). Francolins are also influenced by the season of burn. It was found that in spring francolins prefer unburned grass, and in the autumn they prefer the most recently burned grass. Densities of the birds decline when large areas of grassland are cleanly burned, and it is suggested that a fine-scale fire mosaic would maintain higher densities of the birds (Mentis & Bigalke, 1981).

4.2.5 Insects

Relative to other taxa, direct mortality of insects due to fire may be quite high. The main and longer-term effect is due to changes in vegetation structure, food availability (e.g. grass seed feeders affected), and changes in microclimate. Many species move nests further underground in response to higher surface temperatures as a result of vegetation removal. Arboreal insects may decline after fire (Gandar, 1982). Most species recorded before the fire can fly, and thus have the potential to escape and return.

A study on termites in Nylsvley revealed that no dead termites were found in the colony immediately after burning, but general abundance in the burned area declined for up to a month after the burn (measured from numbers of termites recorded at baits) (Ferrar, 1982). Biomass of grasshoppers also declined on burned areas and there was a corresponding increase on nearby unburned areas, probably due to dispersal to these

refuge areas. Another study on grasshoppers in KwaZulu-Natal revealed that species richness and abundance decreased from annually to triennially burned plots. Burning in the first week of August was more favourable for grasshopper assemblages than burning in autumn or after the first spring rains, and a rotational winter burning programme for the conservation of grasshoppers and other invertebrates was recommended (Chambers & Samways, 1998).

Ants were also found to be sensitive to burning. A study in the Pilanesberg National Park demonstrated that both time-since-fire (fuel age), and frequency of burning affected ant community composition. These results suggest that any conservation plan to conserve biodiversity should allow for a range of frequencies, in addition to a range of post-fire fuel ages, or risk the loss of elements of biodiversity (Parr, 1999). Following a fire, ant communities temporarily change, with overall abundance increasing, but with dominance by only one or two species. The effect of fire on ants is also being investigated in the Kruger National Park. Preliminary results from this study investigating the effect of frequency, season and fuel age suggest that particular burning treatments result in distinct ant communities. It is likely that different functional groups of ants are likely to be affected by fire in different ways, although this remains to be investigated. The effects of fire on ants has also been studied in the fynbos of South Africa, where it was found that ant species diversity was greater on recently burnt fynbos (three month and four year fynbos) and lowest on old fynbos stands (39 years old) (Donnelly & Giliomee, 1985). It is not yet known why there is an in-

crease in diversity of ground-dwelling ants after fire, although it has been postulated that it could be related to higher productivity of the new vegetation, or the fact that the removal of vegetation strata forces ants normally occurring on vegetation down onto the ground.

4.2.6 Reptiles and Amphibians

Few studies have been carried out on the effects of fire on reptiles and amphibians. Tortoises are thought to cope with fires through evasion strategies. In rocky areas, they seek shelter in crevices as well as behind rocks as part of a fire-avoidance strategy (Wright, 1988). In more open, less rocky areas, they are thought to escape fire by moving to open, bare patches of ground (Parr & Brockett, pers. obs.). Other reptiles and amphibians also avoid fire by their choice of habitat preference (e.g., damp sites) or by escaping underground in holes, beneath rocks, up trees or into water (Frost, 1984). In Australia, lizards were found to vary in their sensitivity to fire with some species favoured by early hot fires, others by low intensity patchy fires, and some remained relatively unaffected (Braithwaite, 1987). It is likely that African species will also have different requirements in terms of fire regime. However, this still requires further investigation.

4.2.7 Conclusions

Although the influence of fire on certain *taxa* is well known, there remains a need for further research on the effects of fire on fauna. The type, intensity and extent of a burn are likely to be as important as frequency and season of burn, and are important for the survival of many species –

especially less mobile ones. In many areas, a mosaic of burned and unburned refuge patches, which allow for re-colonisation, is probably best for the conservation of biodiversity.

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5

FIRE EFFECTS ON THE MAINTENANCE OF BIODIVERSITY, SOIL AND NUTRIENTS

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5.1 FIRE AND THE MAINTENANCE OF BIODIVERSITY

5.1.1 Forests

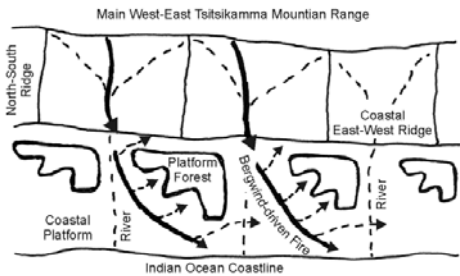
The effects of fire on biodiversity in forests have three different components: (a) fire's effect on the persistence and location pattern of forests; (b) maintenance of forest ecotones; and (c) rejuvenation of forest dynamics when fires do enter forests.

5.1.1.1 Forest Persistence in "Wind Shadow" Areas

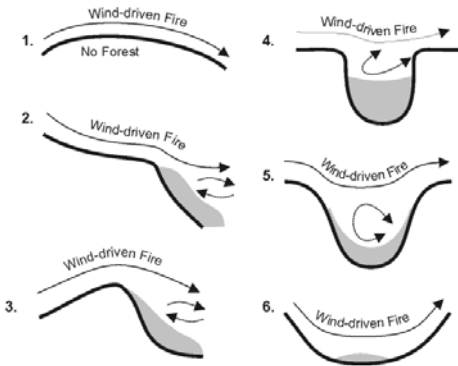
Geldenhuys (1994) showed that environmental factors (rainfall and substrate) determine the potential limits of forest distribution, but that actual forest location pattern is determined by the fire pattern, which in turn is determined by the interaction between prevailing winds during

dry periods and terrain physiography. In the Southern Cape of South Africa, like in many other areas, forests persisted in topographic shadow areas of the gusty, hot, desiccating northwesterly Föhn-like bergwinds which are common during autumn and winter (Figure 5.1). Fires (during bergwinds) would most likely follow the flow direction of the wind and would destroy forests along that route. Such fires would burn with higher frequency in zones in the landscape where forest is currently absent (covered in fynbos and plantations), and would cause calm conditions and a lower frequency of fire in localities where the forests have survived. Forest can therefore recover from episodes of extreme fires, but disappear from areas where fires occur at high frequencies. The flow patterns of air across barriers explained most of the location pattern of forests in the Tsitsikamma:

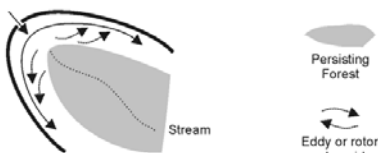
5.1 A. Typical Forest Location Pattern on Tsitsikamma Coastal Platform



B. Landscape Profiles with Remnant Forest



C. Forest in Upper Catchment or Valley



mountains they continue in a south-easterly direction across the coastal platform. This explains the absence of forest on the central platform east of each gorge, but (in contrast) the presence of large forests west of the gorges and the absence of forest on the southern part of the coastal platform.

- The orientation, position and shape of the crest of the ridges on the western and eastern extremes of the southernmost ridges (east-west coastal ridges) have a marked effect on the shapes of the open areas to the west and east of the platform forests (not shown in Figure 5.1-A):

- When the western tip of the ridge points to the north-west, or if the ridge tip east of the gorge is situated further north than the ridge tip west of the gorge, the fynbos area between the forest and the western river gorge is large because of the direct flow of the wind onto the platform.
- When the western tip of the ridge points towards the south-west, the fynbos area between the forest and the western gorge is small.
- When the ridge east of the gorge is situated further south than the ridge west of the gorge, fires burn in a south-westerly direction onto the platform west of the gorge, for a short distance.
- The orientation of the gorge through the platform has no influence on the location pattern of the platform forest. The gorges are narrow and fires can easily jump a gorge.

- The mountains change the flow of the north-westerly bergwinds and channel them with greater velocity southwards through the valleys (Figure 5.1). Their severity is particularly felt in the neighbourhood of a pass or break in a mountain chain (river valley). South of the

Figure 5.1. Schematic view of hypothetical airflow across and around topographic barriers, to show the persistence of forest in wind-shadow areas (Geldenhuys, 1994).

- On the platform, wind of lesser velocity branch away from the main south-easterly airflow to blow in a north-easterly direction. The velocity of the branching wind will depend on the velocity of the main airflow and the velocity gradient between this flow and the wind shadow area in the north-eastern corner of the platform. This explains the pointed-finger pattern towards the south-west along the southern boundary of some forests (Figure 5.1-A). East-west river valleys south of the platform forests affect the flow of the main wind across the platform and prevent the development of the finger-pointed pattern where such valleys exist.
- The shapes (or profiles of obstacles) are also important (Barry, 1981). Sharp breaks of slope create more turbulence in the air passing over them than gradual slopes. Breaks of slope greatly increase the tendency for the airflow to separate from the ground and to form vertical eddies or rotors, *i.e.* air flow in a direction opposite to the wind direction across the barrier (Figure 5.1-B). The intensity of the eddy increases with wind velocity across the barrier and with abruptness of the change in slope between the windward and leeward sides. Furthermore, air tends to flow round an isolated peak, range or ridge of limited length:
 - During a bergwind, air will flow upward in a north-easterly direction on the southern slopes of the southernmost ridge above the platform forest (Figure 5.1-A). This explains the absence of forest on the southern slopes towards the western tip of the ridge. Towards the eastern end, the wind

is calmer and the probability of a fire is smaller. Forest therefore often extends to below the ridge crest on the eastern end (not shown here).

- With a steeper lee than windward slope, the lee eddy will prevent a fire from burning down the lee slope. Forests persist on such slopes to near the crest (Figure 5.1-B2 and B3). Examples are the northern boundaries of Plaatbos (the forest west of the restaurant at the Storms River bridge), and forests of the coastal scarp and river valleys, which extend up to the sharp boundaries with the coastal platform.
- An eddy does not develop with a very gradual change in slope such as a rounded hill (Figure 5.1-B1). Winds will rather slow down towards the valley, because of the rise of hot air at the fire front. Forests in such topographic situations are confined to valley bottoms (Figure 5.1-B6), such as many of the forests in the mountains where the ridges have been eroded to rounded crests near their ends.

A valley between two ridges provides a refuge for a forest to persist (Figure 5.1-C). The ridge acts as an easy route for the wind (and fire), and the wind flow causes an eddy to develop from the valley bottom. If the fire burns from the bottom of the valley, the rising hot air causes it to burn upward along the ridge crest. Very often these patterns are evident as burnt strips in remnants of tall, unburned fynbos indicating the path of previous natural fires.

The implications of these fire effects are that the mountain forests are generally small and more frequently disturbed, whereas the coastal platform forests are larger and less frequently disturbed. Studies of the composition of these forests showed that the associated fire frequency has an important impact on the species richness and dynamics of the forests (Geldenhuys, 1993; 1996b; Geldenhuys & MacDevette, 1989). In general, the mountain forests have low species richness, are dominated by light-demanding species, are in a re-growth stage, and require large gaps for the maintenance of the current forest canopy. By contrast, the coastal platform forests have high species richness, are dominated by shade-tolerant species, are generally in a mature stage, and require small gaps for the maintenance of the current forest canopy.

The results have implications for the interpretation of species-diversity patterns in the landscape in relation to disturbance and recovery, for the application of prescribed burns in catchment management, for the development of fire protection plans for commercial forestry, and for understanding the spread and control of invasive alien plants.

5.1.1.2 Maintenance of Forest Ecotones

The large ratio of forest margin to forest area accentuates the importance of forest margins in forest survival. Forest margins or edges have a more or less fixed position in the landscape as a result of the wind-determined fire patterns. The forest edge can be hard where there is an abrupt change in forest structure (growth form compo-

sition and height) from the forest to the adjacent vegetation, or soft where the change in forest structure is gradual. Under natural conditions, the specific position of the forest in the landscape determines the type of forest edge that can be expected. Where the slope change is abrupt, the edge is usually hard but closed. The bottom end of the forest on a slope usually has a long, soft edge. The forest ecotone, the transition zone between the mature forest and adjacent woodland, grassland or fynbos, often has a species composition of its own, both in terms of plants and animals – another reason why maintenance of a good forest margin is essential.

The shape and condition of the ecotone between the forest and adjacent fire-adapted vegetation will determine the degree to which the forest will be damaged during fires from adjacent vegetation. A soft gradual forest edge, typically dome-shaped, will cause the wind-driven fire to brush over the forest edge. Human-caused forest edges are usually hard, resulting from forest clearing and regular controlled fires. A fire would cause more severe damage to a forest with a hard edge, particularly with accumulated debris (after wind-falls, and tree felling in adjacent timber plantation stands) and dry weather conditions. The frequent controlled-burned fires in the fire-adapted shrublands and grasslands destroyed the natural forest ecotones and prevented the development of the forest ecotone communities (Everard, 1987). This often resulted from block burns with cleared tracer belts, close to the forest edge from where the fire is ignited, during conditions of cool, mild fires.

5.2



5.1.1.3 Forest Dynamics in Response to Fires inside Forests

A recent study has shown charcoal in the litter and feeder root zone of the forest floor in about 30% of the Southern Cape forests, South Africa (Geldenhuys, 1993). No study has yet been made of the charcoal in terms of species composition and age. Such charcoal may originate from fires burning from the outside into the forest understorey (fire at Klein Witelsbos, Blueliliesbush, Tsitsikamma, in 1996), or from spot fires entering the forest from wildfires on the forest margin (Groenkop forest study site in 1996; Noordhoek, Cape Peninsula, 2000), or from honey hunters (Everard, 1994), or from lightning (Geldenhuys et al., 1994). The response to such fires is a rejuvenation of the forest through the development of forest pioneer communities, either from soil-stored long-living legume seeds (Geldenhuys, 1993) or other herbaceous and woody species (Everard, 1994), or from dormant, soil-stored, fern rhizomes (Geldenhuys et al., 1994). For example, the presence of dense stands of the fern *Rumohra adiantiformis* in the forest understorey is often associated with charcoal in the litter and feeder root zone (Geldenhuys et al. 1994).

5.1.2 Woodlands

Species differ in their fire tolerance, and a fire regime may promote certain species and eliminate or reduce other species in the particular communities. Fire is one of the most important ecological factors affecting miombo, and dates back to the Early Stone Age (Chidumayou, 1997). Risk of fire is highest during the hot, dry season from August to November. Flammable biomass in old-growth miombo is 5–8 t/ha (70–90% leaf litter and standing grass), and in young regrowth miombo is 7–12 t/ha (55–70% is leaf litter and grass, and the rest is wood debris from harvesting). Lightning is the natural cause of fires, but natural fires appear to be rare in miombo woodland. The majority of wildfires are considered to be man-made, and occur during the hot, dry season with a return period of 1.6 years. Traditionally, fire was (and still is) used to clear land prior to cultivation and livestock grazing, to make charcoal for iron smelting and to collect honey. Wildfires are used to clear bush and undergrowth to improve visibility around settlements, footpaths and roads, and to keep away dangerous animals (such as snakes and carnivores). The critical factors to consider when assessing the impact of fire in sustainable woodland management are how fire affects the recruitment, establishment, growth and mortality of the key ecological and economic tree species, and hence change in the vegetation. Fire tolerance of miombo tree species consists of three attributes:

- Active growth during early dry season make such species more susceptible to fire damage, such as dominant miombo species, including *Brachystegia spiciformis*.

Figure 5.2. Forest, fynbos and industrial plantations destroyed by a bergwind-driven wildfire during 1999 in the Plettenberg Bay area, Western Cape Province, South Africa (Photo: C. de Ronde).

- Development of vital insulating tissues (such as thick, corky bark, or high wood moisture content), which protect them against fire – most miombo tree species have a moderate moisture content, and few have thick, corky, bark in the young stage.
- Capacity to recover vegetatively – a characteristic of most miombo tree species. Many woodland species develop underground woody suffrutices or swollen root systems, which represent pre-adaptations to tolerate fire, and to grow coppice shoots after the fire (see Boaler, 1966, for *Pterocarpus angolensis*). In general, controlled fire management and protection systems are non-existent to most of the poor southern African countries.

In the Undifferentiated Zambezan Woodland, in northern Namibia (*Pterocarpus angolensis* – *Baikiaea plurijuga* woodland), the recommended fire management system had a twofold objective (Geldenhuys, 1996a):

- A silvicultural management tool to create conditions for regeneration of the desired species, and to increase the survival, the height and diameter growth of existing healthy regeneration.
- A system of fire protection priorities to be followed during times when fires do occur to minimise adverse impact of wildfires.

The desired fire management system was closely linked with the timber harvesting activities. Timber logging disturbance can increase the debris and fire hazard, but protection against fire can

also increase the grass and shrub biomass, which impede regeneration of some species, but also the impact when fires do occur. Fire as silvicultural tool and the fire protection priorities were based on the characteristics and fire tolerance of the different tree species, the vegetation types with which they are associated, and the regeneration status of the specific community or compartment. In general – but especially during the late dry season – fire is detrimental to the regeneration of *Baikiaea plurijuga* and *Guibourtia coleosperma*. Exclusion of fire encourages their regeneration (Geldenhuys, 1977). Two characteristics of *Pterocarpus angolensis* make this species one of the most fire resistant canopy species in the Zambezan woodlands: (a) Its thick, corky bark; and (b) the annual die back of stems in the juvenile stage until the root system is strong enough to produce stems which can survive fire and drought (Boaler, 1966). Trapnell (1959), Calvert (1973) and Geldenhuys (1977) indicated that fire promotes the establishment and development of *Pterocarpus* regeneration. Little information is available on the fire sensitivity of other woodland tree species. *Erythrophleum africanum* is fire resistant (Trapnell, 1959), and it can be assumed that *Burkea africana* is relatively resistant. *Combretum psidioides*, *C. hereroense* or *C. mechowianum* prefers fire protection during the early dry season (Geldenhuys, 1977).

The woodland types were grouped into three management groups to apply burning preferences and protection priorities based on the ecological requirements of the key species of each plant community (see Table 5.1). However, the use of fire as a management tool requires that preventive

Table 5.1. General prescriptions for fire management and fire protection in woodlands in Eastern Caprivi, Namibia.

Management group	Fire management	Protection priority
<i>Baikiaea</i> improvement Regeneration in shrub form	Total protection Burn every 5 years in early dry season	Extinguish fire as soon as possible
<i>Baikiaea</i> improvement Regeneration mainly small trees	Burn every 3 years in early dry season	Limit burning area Allow fire to burn out
<i>Pterocarpus-Baikiaea-Guibourtia</i> improvement	Burn every 3 years in early dry season	Try to contain fire Limit burning area Allow fire to burn out
<i>Pterocarpus</i> improvement	Burn every 2 years in early dry season	Limit burning area Allow fire to burn out
Grassland	Burn annually in early dry season	Limit burning area Allow fire to burn out
Open woodland	Burn annually in early dry season	Limit burning area Allow fire to burn out

5.1.2.1 *The Impact of Fire at a Landscape Scale in the Kruger National Park*

measures must be used when favourable conditions become unfavourable to make protection necessary. Measures to control such fires, both passive preventive measures and active suppression measures, were described in the management plan. These included a system of external and internal fire breaks which should also serve as access roads, and a network of fire lookouts equipped with a suitable communication system, which was considered a requirement for the control of fires. The basic principle followed was that the intensity of fire breaks should not exceed the annual maintenance capacity.

Sources of variability in fire in the Kruger National Park

Fire is one of a suite of "drivers" that influence ecosystem dynamics and heterogeneity. Because fires themselves are dependent on other factors that vary over space and time, they cannot be considered in isolation. The most important sources of variability include soil fertility, rainfall, levels of herbivory, sources of ignition, and variability in the conditions under which fires burn. Soil fertility influences the growth potential and growth rates of grasses and trees, while rainfall influences the biomass of grasses that provide the fuel for fires. Climatic variability will influence

5.3



the occurrence of conditions conducive to the initiation and spread of fires, and herbivory can reduce the fuel loads and thus reduce fire intensity or even prevent fires altogether. Ignition sources can also vary over space and time.

In the Kruger National Park, the main source of variation in soils arises from the differences between landscapes underlain by granites, which are relatively nutrient-poor, and basalts, which are relatively nutrient-rich. Rainfall can vary fourfold annually (from less than 200 to over 800 mm in a given year), and more than twofold spatially (mean annual rainfall ranges from 350 to 750 mm at different locations across the park). Superimposed on different soil types, these sources of variation produce varying quantities of grass biomass, the primary source of fuels for fire.

Regular assessments of grass biomass in the Kruger National Park have shown that these “fuel loads” can vary at any given time between zero and 10 000 kg/ha. Fires will not carry when fuel loads are below 2000 kg/ha, which means that fuel loads can vary fivefold (from 2000 to 10 000 kg/ha) in any year in which fires occur. The climatic conditions conducive to large fires also vary, with only half of the years providing the prolonged hot and dry conditions necessary for large fires to occur (Van Wilgen et al., 2000). These conditions have to coincide with fuel loads in excess of 3500 kg/ha for extensive fires to occur, as they do from time to time, but the frequency of such occurrences over the long term is not known.

The total numbers of important grazing mammalian herbivores (including zebra, wilde-

Figure 5.3. A head fire burning with the wind on the experimental burn plots at Satara. Compare the high flame lengths (which are strongly correlated with fire intensity) to the flame lengths in Figure 5.4, taken minutes later when a back fire burned on the same plot. The photographs clearly illustrate the differences that can occur under the same conditions of weather and fuel (Photo: W.S.W. Trollope).

beest and buffalo) fluctuate in the Kruger National Park, mainly in response to rainfall (Mills et al., 1995), and their biomass has varied considerably in any given year. For example, the numbers of buffalo have fluctuated between 24 000 in 1982 and 8700 in 1993 (an almost threefold difference) in response to rainfall (I.J. Whyte, pers. comm.). Mammalian herbivores and fires would be direct “competitors” for grass fuels, and at times when herbivore numbers are low, fires would be able to burn more area at a higher intensity. Conversely, when herbivore numbers are high, fire occurrence and intensity will be less.

Perhaps the most important source of variability as far as fires are concerned, though, is fire intensity. It is dependant on the amount of fuel available to burn, but also, to a large degree, on the conditions under which fires burn. Byram’s (1959) measure of “fireline intensity” is the most widely used measure of fire intensity, and is usually strongly correlated with the impacts of fire on ecosystems. It is calculated as the product of the heat yield of fuels, the amount of fuel consumed in a fire, and the rate of spread of the fire. Heat yields are measured in J/g, fuel loads in g/m², and rates of spread in m/s, providing units of kW/m. Of the factors in this equation, rate of spread has the greatest range in vegetation fires, varying 1000-fold from 0.1 to 100 m/min. The value for fuel consumed can vary almost 100-fold, from about 100 to 10 000 g/m. Heat yields vary so little (by about 10%) that, for all practical purposes, they can be considered a constant. Fire intensity thus has a practical range of 10 000-fold from 10 to over 100 000 kW/m, primarily due to the large variation possible in spread rates (Stocks

et al., 1997). Intensity levels between 50 000 and 100 000 kW/m have been recorded in numerous boreal zone wildfires, but savanna fires, with much lower fuel loads, probably do not exceed 20 000 kW/m (Stocks et al., 1997).

It has been demonstrated that the type and intensity of fire in the Kruger National Park, and elsewhere in southern African savannas, can have highly significant effects on the responses of trees and shrubs to fire. Higher intensity fires kill the aerial portions of trees, and they can only resprout from the base, whereas less intense fires allow aerial tissues to survive, and the height growth of trees is not affected (Trollope, 1999). Thus a headfire, which burns at high intensity (Figure 5.3), can have quite different effects of the ecosystem when compared to a backfire in the same area under the same conditions of fuel, season, and fire return period (Figure 5.4). Fires that burn at night, rather than during the day, or fires that originate from point ignitions sources, rather than from perimeter ignitions, or “ring-burns”, will have substantially lower intensities. It is thus quite feasible that active management would have had a significant impact on the fire regime in terms of the spatial distribution of fire intensities, and thus fire effects, in the Kruger National Park.

Interpretation from observation

The concerns (outlined above) about the role of fire in the management of the Kruger National Park provided an impetus for the analysis of its effects at scales larger than the experimental burn plots. In the absence of any rigorous vegetation monitoring data before 1985, these have concentrated on fire’s impacts on the woody elements

5.4



of the ecosystem, as these can be quantified from aerial and ground-based photography. A preliminary study (Trollope et al., 1998) used aerial photographs to quantify changes in woody vegetation between 1940 and 1989. These authors were unable to detect any significant changes in the density of large trees between 1940 and 1960, but noted a “dramatic decline” between 1960 and 1989 in all landscapes examined. These results were supported by Eckhardt et al. (2000), who reported a decrease in cover of woody plants (all trees and shrubs), from 11.9% in 1940 to 4.3% in 1998 on basalt substrates, but a small increase (from 19.7 to 22.1%) on granite substrates. However, the Eckhardt et al. study showed that there was an overall decrease in the density of large (> 5m) trees on both substrates between 1984

and 1996. Both studies attributed the changes to interactions between fires and herbivores, particularly elephants.

It is difficult to clearly identify the causes for the observed trends in the absence of an interactive ecosystem modelling framework. In the absence of such a framework, any interpretations must therefore be regarded as speculative. The indications – that woody vegetation had increased on granite substrates, but decreased on basalts – were attributed by Eckhardt et al. (2000) to the dynamics of the vegetation in relation to soil properties. Basalt substrates are relatively nutrient-rich, whereas those on granites are nutrient-poor. In times of drought, grazers remove much of the grass sward on granites, and trees benefit from the reduced competition from grasses (a typical

Figure 5.4. A back fire burning against the wind on the experimental burn plots at Satara. See Figure 5.3 for comparison (Photo: W.S.W. Trollope).

bush encroachment scenario associated with many agricultural areas in the savannas of Africa). This overgrazing may be the result of constant high herbivore numbers, in turn resulting from the artificial provision of water. Park officials also suspect that actual herbivore numbers may be higher than estimates from regular game counts due to an undercounting bias. Although the density of grazing animals tends to be higher on basalts than on granites, grasses can recover from heavy grazing more rapidly on basalt substrates, because of the relative abundance of nutrients, and trees appear not to have benefited as much from reduced competition from grasses in these areas. Evidence for the rapid recovery of grasses on basalts, relative to granites, has been provided by the park's monitoring programme (Trollope et al., 1989), where recovery of grasses after a drought on basalts was more rapid, and reached a higher biomass than on granites. Heavy grazing on basalts may also lead to higher runoff and evaporation (Knoop & Walker, 1985), which means that less water becomes available to woody plants so they gain only little or not at all from reduced competition. The overall decrease in woody vegetation on basalt substrates was therefore attributed to frequent prescribed burning at fixed intervals for over 40 years.

The decline in the number of large trees, on both granite and basalt, needs to be interpreted in relation to interactions between fire and utilisation by elephants. Eckhardt et al. (2000) found a weak relationship between the cover of woody vegetation and fire frequency, with increased fire frequencies corresponding to decreases in cover. The weakness of the relationship suggests that

fire was not the only factor causing the decline, which was most marked in large trees. Elephants also have a marked impact on large trees. The elephant population in the Kruger National Park was estimated, using coarse techniques, to be around 1000 in 1960, although the number (given subsequent estimates) was probably around four times as high. In 1966, the first rigorous count produced an estimate of 6500, and numbers were maintained around 7500 through culling since the early 1970s (Whyte & Wood, 1996). While mature trees can survive frequent fires in African savannas, utilisation by elephants and other animals can damage trees and allow fires to burn exposed areas of wood (Yeaton, 1988). These scars tend to become larger with successive fires, and the trees eventually become structurally weakened and collapse. Frequent, regular, fires (as practiced in the park for a number of decades) would also have served to prevent smaller trees from developing into larger ones, especially in combination with browsing. Thus, increased mortality and declining recruitment of juvenile to adult trees as a result of a combination of increasing numbers of elephants and frequent, regular burning, appear to have resulted in an overall decline in the large number of trees (Yeaton, 1988). This interpretation was supported by Trollope et al. (1989), who showed that exclusion of elephants but not fire also allowed large trees to persist (Yeaton, 1988).

Modelling of impacts

A consideration of the impacts of fire on ecosystems in the Kruger National Park underscores that ecosystems are complex assemblages of

interacting organisms embedded in an abiotic environment. The simulation of the relationships between rainfall, mammalian herbivore biomass, the biomass of grass fuels, and resultant fire extent and intensity, has not yet been attempted in any rigorous way in the Kruger National Park. It has been demonstrated (e.g. Hobbs & Atkins, 1988; Yeaton & Bond, 1991) that spatial variability in fire, even at the scale of small experimental plots, is a significant factor in allowing co-existence of species in ecosystems. However, the need to understand the complexity that arises from inter-specific and intra-specific interactions among individuals, interactions across trophic levels, and interactions of organisms with the abiotic environment over space and time, calls for approaches that can simulate these interactions (Hartvigsen et al., 1998). A fundamental question for fire ecologists is how to predict the impact of a single, discreet event (a fire), or a series of events (fires) on the outcomes that characterise an ecosystem at a much higher level of complexity.

To date, there is only one published account that has rigorously examined the role of fire, in a conceptual model, in determining tree/grass coexistence in African savannas (Higgins et al., 2000). This model – based in part on work done in the Kruger National Park – provides a framework for understanding the conditions that allow trees and grasses to co-exist in a fire-prone and climatically variable environment. The model predicts that wet-season droughts are an important factor limiting tree seedling establishment, while fires prevent the recruitment of trees into adult size classes. The model shows that the effects of

variations in fire intensity on tree demography accounts for tree-grass co-existence, and that removal of this variation can lead to the exclusion of trees. Unlike Walker and Noy-Meir's (1982) model, which is an equilibrial model, variance is central to the co-existence problem. Hence, variable fire intensities provide opportunities for tree stems to escape the flame zone where they are most susceptible to fire, and to recruit into the more fire-resistant size classes. Declines in tree numbers in the model simulation result from continuing, but low-level, adult mortality. The rate of adult mortality, due to factors other than fire, strongly influenced tree persistence in the model. The model suggests that low adult mortality rates (< 0.05) would be necessary for tree persistence, and the authors further point to the estimates of elephant-induced tree mortality rates of 0.18, reported by Thompson (1975) for Zimbabwean savannas, which suggest that the role of elephants as ecosystem modifiers "should not be disregarded". Higgins and his co-worker's model supports many of the speculative explanations put forward by researchers seeking to explain the decline of trees in the Kruger National Park, and provides a useful framework for guiding a monitoring and evaluation programme for the park, by pointing to the key parameters which influence the co-existence of trees and grasses.

Are large fires different?

While the role of fire as a natural disturbance capable of shaping landscapes and influencing ecosystems is well recognised in ecology today (Bond & Van Wilgen, 1996; Whelan, 1995), the effects of very large and infrequent fires is less well under-

stood. Fires sometimes qualify as “large, infrequent disturbances” (LIDs) (Turner & Dale, 1998), which are loosely defined as those disturbances that are much larger in spatial extent or duration than those that typically affect the ecosystem in question. For example, 1–3% of fire events account for 97–99% of the landscape burned in some ecosystems (Bessie & Johnson, 1995). The literature in this regard focuses on fires as LIDs in boreal forest systems (e.g. Foster et al., 1998), and this aspect of fires in savannas is less well understood. The type of response to a LID can be either continuous (independent of the size of the disturbance), scale dependent, or of a “threshold” type. Threshold responses are defined as those in which the response curve shows a discontinuity or a sudden change in the slope along the axis of increasing disturbance extent, intensity or duration (Romme et al., 1998). Such a point would be reached when the size or intensity of the disturbance exceeds the capacity of the internal mechanisms to resist disturbance, or where new mechanisms become involved. Understanding the consequences of LIDs is important for management. We need to know whether or not the substitution of smaller, more controllable disturbances (such as prescribed fires) for dangerous, uncontrollable fires could actually achieve the management objectives of conserving all elements of the ecosystem. Romme et al. (1998) concluded that LIDs differed from smaller-scale disturbances in some, but not all, ecosystems by exhibiting threshold qualities that could cause the ecosystem processes to bifurcate. This could happen when species that would normally survive smaller fires are unable to survive or recolonise

after larger fires. In some cases, more than one LID is necessary to cause a long-term alteration in the state of the ecosystem, underscoring the importance of sequences of disturbances such as fires. Evidence of thresholds reached after large fires is lacking for savanna ecosystems. Fires that could be regarded as LIDs may have occurred in 1953 and 1996 in the Kruger National Park. The 1953 fires covered 25% of the park, and the 1996 fires burnt 36% of the area burned in the eight years between 1992 and 1999, and covered 22% of the park. However, the fires do not appear to have had any dramatic effects on the ecosystems in the medium term, indicating that they fit into Romme et al.’s category of “scale-independent” responses. This conclusion would support the idea that substitution of occasional large fires by a series of prescribed burns would not have any negative effects on the ecosystem.

5.1.3 Fynbos

Fynbos is the world’s richest extra-tropical flora and conservation of its biodiversity is a topic of wide public interest and concern. Intelligent use of fire, together with clearing of invasive trees and shrubs, are the two most important management interventions for managing biodiversity. In this section, the ecological principles for fynbos management are briefly described.

Fynbos is a fire-dependent ecosystem and thousands of its component species require fire to complete their lives. It is not possible to maintain biodiversity of this system without periodic burning. Since fynbos vegetation often abuts onto urban areas, housing settlements, farm buildings as well as other developed landscapes,

difficult decisions have to be made on how to burn so as to maintain biodiversity while also ensuring safety of lives and property.

Ecological principles for fynbos burning have been heavily based on studies of the tall proteoid shrubs that often form an overstorey of fynbos communities. There are several reasons for this emphasis on proteas:

- The plants are attractive and economically important in the wildflower trade.
- Many species are killed by fire and depend entirely on stored seedbanks for regeneration.
- They are the slowest maturing fynbos shrubs. They therefore define the minimum interval for safe burns that will ensure successful regeneration of fynbos species.
- Because they form the overstorey, proteas shade understorey plants. Since fynbos species are generally intolerant of shade, the protea overstorey strongly influences community diversity.
- They are relatively easy to work on (plants can be aged, seedbanks estimated and post-burn skeletons remain for some years allowing post-burn analyses).

Maintenance of biodiversity requires consideration of the fire regime. This is the mean and variance in fire frequency, season, severity and area of burn. The type of fire is always a crown fire in these shrublands. Fire frequency is the mean for return interval. If the interval is too short, non-sprouters can be extirpated because there is insufficient time to accumulate a seedbank. This

is a common problem in serotinous proteas, which only mature after three to ten years, depending on the growing conditions. If the fire interval is too long, certain species may also be extirpated. This is because plant lifespans are relatively short and the lifespan of seedbanks is finite. Again, serotinous proteas are particularly vulnerable to long fire intervals because plants die, releasing their seeds, after 30+ years without burning. Very few seeds produce seedlings, unless they fall into a post-burn situation.

Impacts of protea shading on understorey species also increase with the length of the fire interval. Some studies show that shading by proteas does not harm, and can actually promote, overall fynbos community diversity. However, long episodes without fire are likely to have negative impacts as the understorey plants die, and their seedbanks decline. Long fire frequencies are becoming an increasing problem in small fragments of fynbos on farmland or municipal reserves where there is a high-perceived risk in planned burning operations. Though recommendations will vary in different localities, fire frequencies between about 10 and 30 years will be safe for most species. Minimum (as well as maximum) intervals can be longer (15 years) in more arid areas, or guided by the rule that areas should not be burned until most proteas have flowered at least three times.

Fire season also influences fynbos regeneration. Lightning fires probably occurred in the summer months, but safety considerations have led to shifts to autumn or winter burns. Winter burns (June, July, August) often produce very poor protea recruitment. Autumn burns (March, April)

generally promote protea seedling recruitment. Many understorey species also regenerate best in autumn burns and worst in winter. Winter burns may promote some species of Asteraceae (e.g. *Stoebe* and *Metalasia*), which can become a problem if they reach high densities. They suppress other species and create fuel hazards. Sustained winter burns are not advised for maintaining diversity. Autumn burns, however, can also cause problems by creating such high densities of some proteas that plants are crowded out. A mix of summer and autumn burns, and rare winter burns, is probably optimal.

Fire severity is measured by the amount of biomass burned. The most severe burns occur under hot, dry, windy conditions in old stands with large amounts of dead fuel. These are likely to have been common conditions under which natural fires once occurred. Safety considerations have caused a switch to low-severity fires for most planned burning. The response of fynbos species to fire severity is still poorly researched. Our current understanding is that species with large ant-dispersed seeds regenerate well after severe burns and poorly after low intensity burns. Small-seeded species seem to follow the opposite pattern with poor recruitment after severe burns. A mix of fire severities would be best for diversity. In areas where safety is an important consideration, large-seeded species might be at some risk. In areas with high fuel loads, such as those invaded by aliens, small seeded species are more likely to be lost. Fire severity effects on diversity are greatest on deep soils with few surface rocks. Rocky sites have more variable soil temperatures during a burn and few species are

adversely affected. There is also growing evidence that very severe burns can kill resprouting plants. Since such plants seldom recruit successfully from seedlings, a single severe burn may have long lasting effects on fynbos composition.

The burn area can affect fynbos regeneration in several ways. Very small burns (< 10 ha) have sometimes been used to stimulate rare species regeneration. Unfortunately, these small burns attract mammal browsers and rodents from adjacent vegetation. The intense post-burn herbivory can cause recruitment failure. Burn size may also be important in maintaining viable populations of non-sprouting serotinous proteas. This is because local extinction is common in such species. Suitable habitat can only be recolonised from seeds dispersing to it in the weeks following a fire. The seeds, in turn, need a source in the form of a surviving stand, burned in the same fire, and within dispersal distance. Proteas are a rare example of a so-called “meta-population” where extinction of local sub-populations is not uncommon and the whole population persists by dispersal among sub-populations. Barriers to dispersal among sub-populations, whether by roads, cropland, or unburned areas, will increase the risk of extinction.

5.1.3.1 Other considerations

At the end of the 20th century, the fynbos biome experienced successive hot, dry summers. These not only led to very large severe fires, but also to widespread mortality of drought-sensitive species in unburned vegetation. Fynbos recruitment is very often fire-simulated. Drought death kills plants, but does not provide the appropriate

conditions to stimulate recruitment. If such droughts increase in frequency, as predicted by some global change scenarios, we may see very rapid loss of fynbos diversity. Drought-related seedling deaths after a burn could also lead to very rapid loss of non-sprouting species. Many fynbos elements are very sensitive to rapid extinction because of their non-sprouting life histories. The interaction between fire and intense prolonged drought is a new problem and a disturbing one for the future of fynbos diversity. Longer fire intervals might be one way to reduce exposure of plants to recruitment failure due to the combination of severe fires and prolonged drought. We need to approach the problem with great care.

5.2 FIRE EFFECTS ON SOIL AND NUTRIENTS

5.2.1 Introduction

The effects of fire on physical soil properties are particularly related to the period of time and intensity of fire temperature exposure, and parameters such as soil structure and soil texture. The same applies to the effects of fire on the chemical properties of the soil, such as nutrient budgets, nutrient availability and nutrient cycling. These effects are complex and they differ from one ecosystem to the next; even from one site to another within ecosystems. The effects on the soil also change significantly with time after fire occurrence. Sites exposed to fire have the ability to “adjust themselves” over time, as numerous “correction mechanisms” are “turned on” within the ecosystem subjected to fire.

In this section only the most significant effects will be discussed shortly, but the reader should note that these notes are of a general nature, and not applicable to any particular system, site or fire, that has occurred.

5.2.2 Fire Effects on Physical Soil Properties

If the forest floor above the soil surface is not completely removed by a fire – such as after light intensity prescribed burning – a fire will have negligible effects on soil heating and subsequent heating effects. If the forest floor is completely consumed, the underlying soil is exposed, and thus vulnerable to e.g. rainfall impact. Soil aggregates are dispersed, pores can become clogged and infiltration and aeration can be decreased (De Ronde, 1990; Wells et al., 1979). When prescribed burning is applied in natural vegetation or industrial plantations, care should be taken on fine-textured soils on steep terrain (Pritchett, 1979).

Volatile hydrophobic organic compounds, derived from plant residues, can move into the vapour phase downwards into the soil profile, away from the heating front caused by fire. These compounds then condense and chemically bind to soil particles to produce water repellent layers, which may further contribute to runoff after a fire (DeBano, 1967). The severity of this water repellency is related to soil texture, fire intensity and soil water content. It is particularly in coarse texture soils that organic matter can induce water repellency and thus restrict water movement (DeBano, 1967; 1981).

The combustion of the organic matter causes soil to lose its plasticity and electricity, physical characteristics relevant to soil erosion processes

(Giovannini et al., 1990). Exposure of the soil surface, through destruction of the vegetation cover, especially after repeated fires, may permit even severe erosion and accelerated surface-water runoff (Davis, 1959).

Forest litter greatly reduces runoff, especially in fine textured soils, and destruction of litter by fire and subsequent exposure of bare soil greatly increases soil erosion, which will reduce the water absorption rate. Pores are also sealed by particles during the runoff process, and soil infiltration is also reduced, thus high intensity fires on steep slopes can cause a significant increase in soil erosion where all vegetation and litter is removed by the fire, particularly after heavy rainshowers (De Ronde, 1990). It is thus clear that more precipitation flows off from burned than from unburned sites and the more the runoff is concentrated and therefore able to detach and transport soil particles, the greater the potential for soil erosion (Marxer et al., 1998).

It is recommended that exposure of steep slopes (with erosion potential) to high intensity fires should be avoided, and that these sites should rather be treated with more frequent (light intensity) prescribed fires.

The effect of fire on soil-moisture content is extremely variable. The immediate effect of soil exposure following fire is to reduce soil moisture, especially near the surface. Heavier soils may be affected by compaction after repeated fires when the mineral soil is exposed. Infiltration capacity is then reduced. Sandy soils are seldom affected in this way (Davis, 1959). In savannas fires have little direct impact on soils. This is primarily due to low temperature elevation and short residence

time of elevated temperatures during fires (Savage, 1980; Frost & Robertson, 1987). Increases higher than 10°C generally occur only in the top 15 mm of the soil; below 15 mm the temperature increases decline exponentially with depth, where the extent of soil temperature increases with soil moisture, which increases transfer of heat through the soil (Cass et al., 1984; Frost & Robertson, 1987; Van de Vijver, 1999). The effect of fire on the physical soil properties is primarily due to the indirect effects as a consequence of biomass removal (Cass et al., 1984; Frost & Robertson, 1987; Van de Vijver, 1999). Of these effects, the effect on soil moisture content, a prime determinant of savanna systems, is the most prominent.

Apart from amount and intensity of rain, slope and soil physical properties, aboveground biomass is a prime determinant of soil moisture content in savanna systems (Fischer & Turner, 1978; Van Wijngaarden, 1985). Aboveground biomass can have positive as well as negative effects on soil moisture content. Positive effects are through reduced run-off, increased infiltration rates and lower evaporation rates, and negative effects are through increased interception and transpiration due to increased area transpiring surface (Savage, 1980; Eldridge, 1993; Scholes & Walker, 1993; Van de Vijver, 1999). For example, soil temperature of post-burn soil can be significantly higher than that of unburned vegetation (Savage, 1980), with temperatures in top soil of a burned site reaching up to 80°C, compared to 23°C in an adjacent unburned site (Van de Vijver, 1999, unpublished). The increased soil temperature in combination with open conditions, which allow increased wind

speed at the soil surface, cause increased evaporation and consequently accelerated drying of soil (Chase & Boudouresque, 1987). This increased loss of water is particularly prominent when fire has removed large quantities of litter, which has a much stronger insulatory effect over soil as compared to standing biomass (Van de Vijver, 1999). Standing biomass does however contribute to reducing run-off since, like litter, it reduces the physical impact of rain on the soil during heavy showers, thus reducing soil compaction and increasing infiltration (Scholes & Walker, 1993).

Finally, apart from biomass removal, infiltration may also be reduced after fire by the formation of organic aliphatic hydrocarbons during fire that are deposited on the soil, causing water repellency of the soil (Wells et al., 1979).

Removal of biomass through fire may also positively affect soil moisture content. Particularly when fire has removed large amounts of above-ground biomass, interception of water during rainfall is significantly reduced, thus increasing the amount of water able to enter the soil (Dunn, 1987; Eldridge, 1993). This positive effect primarily occurs when rain showers are light (Van de Vijver, 1999).

Fire may also reduce the transpiring leaf surface and accordingly improve the vegetation's water status. This may even result in a temporary growth stimulation at the end of the growth season (McNaughton, 1985), a period in which soils dry up and vegetation growth is retarded and above-ground vegetation dies off due to lack of available water. Because this flush of highly nutri-

tious forage is readily grazed, and consequently plant carbon and nutrients for storage is lost, the vegetation has no advantage of this burning practice (Edroma, 1984; Edwards, 1984a; 1984b).

The loss of vegetation cover through fire, and subsequent grazing at the beginning of the dry season, leads to loss of soil water, which is crucial for plant survival during the dry season. This practice of early dry season burning can lead to a decline in vegetation production in the following growing season and a deleterious effect on perennial species (Edroma, 1984; Edwards, 1984a; 1984b; Bond & Van Wilgen 1996).

Generally speaking, the negative effects of fire on soil moisture content overrule the positive effects in savanna systems, and consequently post-burn soils have lower moisture content than soils of unburned vegetation (Cass et al., 1984; Busch & Smith 1993; Van de Vijver, 1999). The level at which effects are detrimental depend on season of burning, soil properties, annual rainfall and post-fire rain conditions.

From a management point of view, the effects of fire on the water balance certainly should be considered when it comes to the planning of long-term fire regimes, particularly in the semi-arid and arid regions. Here water is the prime determinant of vegetation growth and development, and regular use of fire should be restricted. In many of these regions rainfall is also erratic (Pratt & Gwynne, 1977), and hence the effects of fire on the water balance may aggravate these (already occurring) negative effects of a dry period on vegetation production (Van de Vijver, 1999).

5.5



5.2.3 Fire Effects on Chemical Soil Properties

The effect of fire on chemical soil properties is complex and variable, but generally the changes are most pronounced in the topsoil (Davis, 1959; De Ronde, 1990; Van de Vijver et al., 1999; De Ronde & Zwolinski, 2000). The mechanisms through which fire affects chemical soil properties can basically be described as (a) the process where minerals are released by combustion and left in the form of ash, and (b) microclimatic changes resulting from fire, which affect decomposition and mineralisation rates. The most immediate effect of burning is the release of mineral elements. These mineral nutrients are either released in forms available to plants through ash deposition, or are lost through volatilisation and ash convection. The deposition of nutrients can

be such that plant growth is stimulated through the increased supply of nutrients via the ash, the so-called "Ash bed effect" (Walker et al., 1984; De Ronde, 1990).

The effect of fire on chemical soil properties and the ash-bed effect depend on various factors such as soil texture, structure, total amount of nutrients in the soil (Boerner, 1982; Van Reuler & Janssen, 1996; Van de Vijver et al., 1999), the below- and aboveground nutrient distribution, the nutrient concerned, weather conditions, the phase of vegetation growth, fire intensity and fire frequency. For example, in forests the ash-bed effect is particularly common on clayey topsoil with very low P-levels, where the nature of compounds formed apparently represent specific pH conditions and mineral components in the soil

Figure 5.5. Slash pine (*Pinus elliottii*) stand with ash layer, days after prescribed burning.

(McKee, 1982). On sandy soils, conversely, leaching of plant available nutrients may be rapid, and may even decline after fire, and as a result nutrient pools decrease rather than increase, as has been preliminary observed. However, in almost all cases, pH and nutrient levels will return to pre-burning levels within a few years (De Ronde, pers. obs.).

Generally, light intensity prescribed burning in forests has very little effect on the nutrient status of most soils, while slash burning of even-aged timber stands in industrial plantations can have some effect on nutrients, depending on the burning methods used (e.g. broadcast burning vs. slash piling and burning, the latter having a more detrimental effect because of the high fire temperature exposure for longer periods of time) as well as the soil texture and structure (De Ronde, 1990; De Ronde & Zwolinski, 2000). Intense repeated burning generally has a negative effect on soil chemical properties, first reducing the soil organic matter, which subsequently contributes to loss of mineral nutrient through leaching next to the loss caused by volatilisation and run-off. In most cases, light to moderate fire intensities can stimulate growth of plant and tree communities in the short-term. Although nutrient availability may even improve soon after high intensity fires have been experienced, the longer-term effects are normally detrimental on nutrient budgets, but this also depends on the soil texture and structure (Davis, 1959; De Ronde, 1990).

In many other natural vegetation communities, such as Fynbos and Macchia, a surface enrichment of nutrients can be experienced as a result of the effect of the addition of ash to species com-

position and structure of the burned vegetation, its litter and elements (Kutiel & Naveh, 1987). The increase of exchangeable cations as a consequence of fire, with similar values than those on unburned sites, can also be a prominent feature (Trabaud, 1983; Iglesias et al., 1998). In savannas and many sub-Saharan grassland systems, where fire is a common phenomenon, fire can play a significant role in nutrient dynamics. Indeed, when considering loss of nutrients from above ground pools during and after fire, these can be up to 96% for nitrogen (Table 5.2). However, the consequences for the total nutrient pool are related to the amount of aboveground nutrients. With grass being the most dominant growth form in savannas, which primarily burns during the dry season when growth is retarded and nutrients have been relocated to storage organs, nutrient losses from the total pool as result of a single fire are negligible (Table 5.2; Van de Vijver et al., 1999). The ash-bed effect can only be regarded as of minor importance when explaining the enhanced plant nutrient content in post-fire regrowth. This is particularly the case in the more nutrient-rich savannas. This is also demonstrated in Table 5.2 where the amount of nitrogen in the "ash-bed" corresponds with the amount of nitrogen released via mineralisation in two days. The causes for enhanced post-fire plant nutrient concentrations, generally found in savannas, are related to the increased leaf-to-stem ratios, with leaves inherently having higher nutrient concentrations, rejuvenation of plant material and reduced dilution of nutrients as a result of lower levels of standing biomass, compared to unburned vegetation.

Table 5.2a. Averages of above- and belowground (0-10 cm) nutrient pools (g m^{-2}) in a semi-arid savanna, northern Tanzania, before and after burning. The amount of nutrients lost through volatilisation and ash convection is expressed as a percentage of the aboveground as well as total nutrient pool before burning.

	N	P	K	Ca	Mg
Total soil nutrient pool (g m^{-2})	118	33	313	176	303
Above-ground nutrient pool prior to fire (g m^{-2})	2.02	0.31	1.32	1.77	0.33
Nutrients in ash after fire (g m^{-2})	0.15	0.21	0.53	1.02	0.29
Nutrients lost from above-ground nutrient pool (g m^{-2})	93	32	60	42	12
Nutrients lost from total nutrient pool	1.6	0.30	0.25	0.42	0.01

Table 5.2b. Organic matter (OM, %) and pH in the top 10 cm soil prior to implementation of treatments (TO) and one month later in burned, clipped and control plots as well as soil nutrient release ($\text{mg m}^{-2} \text{ day}^{-1}$) during the first month (December to January) after implementation of treatments (n). Different superscript letters indicate significant differences between treatments for $P < 0.05$ (Van de Vijver, C.A.D.M. et al., 1999).

	Soil nutrient release						
T0	OM	PH	N	P	K	Ca	Mg
	4.19 ^a	5.84 ^a					
Burned	4.09 ^a	5.98 ^a	58.3 ^a	5.44 ^a	140 ^a	441 ^a	122 ^a
Clipped	4.16 ^a	5.86 ^a	46.6 ^a	6.27 ^a	67.2 ^a	278 ^a	99 ^a
Control	4.08 ^a	5.93 ^a	51.5 ^a	6.51 ^a	115 ^a	413 ^a	133 ^a

Apart from direct ash deposition, fire may also affect chemical soil properties and hence soil nutrient status through various indirect effects. As already stated, temperatures of the soil on post-burn sites may be enhanced. When low temperatures inhibit soil microbial activity, the increase in temperature may stimulate mineralisation rates and subsequently available soil nutrients for

plants. Soil microbial activity may also increase after fire, as C/N ratio's of deposited ash and remaining organic material are reduced, which allows higher rates of decomposition.

Various studies report of increased mineralisation in post-burn soils (Savage, 1980), but other studies also found no effect (Van de Vijver et al., 1999; Table 5.2) or a decline in mineralisation

(Brookman-Ammisah et al., 1980), which can be related to a reduction in soil moisture which can have negative effects on soil microbial activity. When large amounts of aboveground biomass have been burnt, fire normally increases pH. This effect favours bacterial population growth over fungal population growth. The ash from most plant materials is high in ions of the major elements, such as calcium, potassium and magnesium. This tends to increase the pH of acidic soils, especially of sandy soils that are poorly buffered (Chandler et al., 1991). Soil acidity in the surface layers is reduced by burning, as a result of the basic cations being released by combustion of organic matter and minerals (Wells et al., 1979). On the other hand, on more alkaline soils the effect of fire on soil pH is negligible and has no clear consequences for ecosystem properties and dynamics. Increases in pH are also marginal in the case of light intensity prescribed fires, which are normally not sustained (McKee, 1982; Viro, 1963). However, in the case of high intensity wildfires, these increases can be more substantial and sustained (De Ronde, pers. obs.).

Table 5.2 also demonstrates the variability of various nutrients in response to fire. For one thing, this is related to how volatile the element is. Nitrogen, together with sulphur, forms one of the more volatile nutrients with significant losses occurring above 400°C (Frost & Robertson, 1987). Apart from volatilisation, nitrogen also leaches easily (Harwood & Jackson, 1975) which can result in additional loss when plant growth is low and nitrogen is not absorbed readily. Generally nitrogen is the most limiting nutrient for growth in natural terrestrial systems and, with high loss

rates through fire, one would expect a long-term negative effect of fire on nutrient concentrations. However, nitrogen is also unique in that it can be replenished after a fire by biological nitrogen fixation (Dunn & deBano, 1977). This process, combined with wet and dry deposition may contribute to the fact that generally long-term negative effects of fire on the nitrogen budget are not found or not as apparent as would be expected (Frost & Robertson, 1987).

Phosphorus, another macronutrient generally limiting for both plant and animal life, has a much higher volatilisation temperature of 500°C and is also much less susceptible to leaching (Frost & Robertson, 1987). In forests, many researchers have recorded more phosphorous availability and a stimulation of tree growth following burning, provided the nutrients were not leached out or eroded away before plants could utilise them, such as in sandy soils. In acid soils such increases can persist for several years as a result of lack of phosphorus movement, on account of its tendency to react with iron oxides and aluminium, which occur in relatively high concentrations (particularly) in heavy soils (Bara & Vega, 1983; Davis, 1959; McKee, 1982; Vega et al., 1983). Moreover, when soil pH is increased through fire, P availability may also increase. Some increases in available phosphate on clayey soils with low P-levels not only resulted in increased *Pinus elliottii* tree growth rates after tree establishment, but these increases were maintained up to seven years on the Tsitsikamma plateau in South Africa after broadcast slash burning (De Ronde & Zwolinski, 2000).

Increases and decreases in topsoil nutrients, other than N and P, have been recorded and,

particularly after high intensity wildfire, nutrient losses are common, and mostly in the order of $Mg > P > K > Ca$ (Harwood & Jackson, 1975; and own observations). As with N and P, the changes in concentrations of other nutrients is related to their volatility and mobility. Sodium for one is not volatile but highly mobile and when heavy rains follow fire this nutrient is easily washed/leached away from the plant root zone. Because of high volatilisation temperatures and low mobility, one generally finds higher concentrations of Ca and Mg in post-fire soils or when one does find lower values these are attributed to surface erosion and ash dispersal (Busch & Smith, 1993). Here too, the degree in which alterations of these nutrients is of ecological importance, and depends on the pre-fire above and below ground nutrient pools.

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6

REGIONAL FIRE MANAGEMENT: OBJECTIVES, PRACTICES AND PRESCRIBED BURNING APPLICATION

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6.1. INTRODUCTION

Some regions in Africa, south of the Sahara, are faced with unique fire management requirements, which are either linked to specific ecological needs, man-introduced problems, land-use or a combination of these. To overcome these obstacles, fire managers are sometimes faced with challenging objectives that are aimed at particular site-specific management objectives, while simultaneously maintaining the biodiversity of the ecosystem base. These decision-making processes can be influenced by regional problems such as population pressure, industrialisation or other region-specific demands, such as grazing requirements, water availability and the protection of rare natural heritage objects.

In this chapter the particular fire management/ecological requirements for some regions will be discussed, which the writers have identified as deviating significantly from globally – or more

fundamental regional – fire regimes described elsewhere in this book.

6.2 FIRE MANAGEMENT IN THE WESTERN CAPE, SOUTH AFRICA

6.2.1 Considering Fire Use in Weed Infested Areas

On most cultivated land in the Western Cape, weeds are effectively controlled by annual crop rotation. However, outside these lands, such as along river courses, in mountain catchment areas, in nature reserves and in areas not regularly managed for cultivation or grazing, some serious weed problems have developed, threatening the survival of natural fynbos vegetation. Indigenous biota are displaced and species diversity is reduced, where alien invasives have an impact on physical processes necessary for the maintenance of the biota, therefore clearance of such land is

required to achieve the aims of nature conservation (Van Wilgen et al., 1990). Industrial plantations in the Western Cape only cover a small area of the land in the Western Cape Province, but field observations show that they form an important source of aline invasives into nature conservation and catchment areas (particularly *Pinus pinaster*).

In fynbos there are two broad groups of woody alien weeds. The most important group includes plants such as *Hakea sericea* and *Pinus pinaster*, which are killed by fire and then release their seed stores on the death of the parent plant. These should then be felled, and left to dry out for some period of time, before this fuel should be burned. The fire will kill the seedlings, but regular follow-up operations will be necessary to ensure that survivors are eliminated. In fynbos, follow-up weeding operations are generally carried out 2.5 and 10 years after fire (Macdonald et al., 1985, cited in van Wilgen et al., 1990). The current clearance method of felling and burning for dense (> 90% canopy cover, 90 000 stems/ha) alien stands, is effective in controlling serotinous species in mountain catchments. However, where post-fire alien densities are low, intensive follow-up clearance will be required (Holmes & Marais, 2000).

The second group includes those species with continual seed production and release (for example the Australian *Acacia* species). Large quantities of hard-coated and persistent seeds accumulate in the soil. Here control is more problematic. Felling and burning results in an abundance of seedlings, needing clearing by hand pulling, which is a time-consuming and labour-

intensive operation (Van Wilgen et al., 1990). *Acacia* species, such as *Acacia longifolia* and *Acacia mearnsii*, are particularly problematic along river courses in the region, while *Acacia cyclops* has taken over old drift sand reclamation areas along the coast. This species has accumulated enormous biomass over the past 40 to 50 years, resulting in extremely high fire intensities when wildfires are experienced. As a result, the control of *Acacia* regeneration proved to be very costly. However, if not controlled, the seed stores of these aliens will produce even denser weed thickets in years to come if fire does not intervene.

In most cases where large weed infested areas occur in the Western Cape, a systematic felling and prescribed burning programme, followed by a regular regeneration control programme, is the only answer to convert alien-infested fynbos back to its indigenous condition. The problem not only lies in attending to these operations, but also in erasing alien seed store regeneration after wildfires. Failing to do so will increase alien tree and shrub density even further, particularly in the case of *Acacia*.

6.2.2 Scheduling and Maintaining Prescribed Burning Programmes

Most of the prescribed burning in the Western Cape is applied in the fynbos biome of the region. Application of fire on agricultural land is mostly limited to burning crop residues after harvesting and the burning of some strategic fire breaks, particularly before wheat crops mature. Industrial plantations form a small (and decreasing) percentage of the land in the Western Cape, and as a result, prescribed burning scheduling, though

important, does not require special attention.

Prescribed burning requirements in fynbos – though complex – have been determined in broad terms after many years of research, and does not present a problem. Optimum season of burn of fynbos may leave nature conservators with a rather restricted burning season (Chapter 5). However, optimum use of suitable burning days – and clearly set burning priorities – will assist fire managers in reaching their goals. Weed infestation presents a more serious problem for prescribed burners, as some fynbos areas have developed abnormal fuel loadings. Fortunately, the “working for water” project (Van Wilgen et al., 1990) is steadily reducing the size of these weed problem areas, through systematic weed control and fire application. The hundreds of thousands of hectares that were burned in wildfires during the late 1990s have also assisted in reducing the size of the problem, though only temporarily, as regeneration of weeds will have to be checked regularly thereafter. However, it is necessary to consider the *status quo* carefully, and to continue scheduling prescribed fire for unburned areas, with clearly set goals and priorities.

The urban interface problems also require urgent attention, as new townships (formal and informal) are developing at a fast rate. Conflict situations appear overnight, and nature conservators and township planners will have to come together on a regular basis to address these problems. It is suggested that firstly fire managers of the region should create a flexible integrated fire management plan, and then hold (at least) twice-yearly meetings with all disciplines (before and

after the fire season) to schedule prescribed burning programmes and check progress.

6.2.3 Fire Management in Agricultural Areas and Forestry Plantations

On most farms in the Western Cape there is a percentage of the land that is not intensively cultivated, nor is it used for grazing purposes. On these properties fire management should be dealt with as explained in paragraphs 6.2.1 and 6.2.2. In areas where vineyards or fruit orchards form a significant part of land use, very little may be created in terms of burnable material, and fuel management is normally limited to removal of pruned branches, which are normally burned in heaps. Weeding may also be required from time to time to keep the soil surfaces free of vegetation underneath the trees/vines, or between the rows.

Vineyards and orchards can be damaged by scorch from wildfires, or by fire burning through dry grassy understorey vegetation, when wildfires enter orchards. For that reason fire breaks should be maintained between areas covered by natural vegetation (such as fynbos), industrial plantations, vineyards and orchards. Where fynbos is maintained for wildflower production, care must be taken to burn older fynbos systematically when flower productivity is reduced by old age, to ensure sustainable flower yields. These burning programmes must be based on ecological principles, as explained in Chapter 2. These areas must also be protected against wildfires by means of external fire breaks.

Where wheat is grown, care must be taken that fire breaks are placed between these lands and public roads, informal settlements and

railway lines, before the crop reaches maturity. Burning of crop residues after harvesting of wheat lands is also recognised as a useful fuel reduction measure and for fire protection purposes, particularly in both the Swartland and Overberg districts. Fire breaks should preferably be prescribed-burned, but ploughing of strips along such boundaries can also be used effectively to protect crops against fire.

Where sheep or cattle farming is practised, systematic grazing is a particularly effective fuel management measure. However, in any land that is left ungrazed for some period of time, burnable vegetation can accumulate, and subsequently an increase in fire hazard can be experienced. The use of rotational grazing will avoid such a potential hazard, but natural vegetation, particularly along rivers and land too rocky for cultivation, must be protected by regular prescribed burning and/or external fire breaks.

Although industrial plantation forestry is only practised on a small percentage of the land in the region, and is phased-out in places, it often creates a conflict situation with adjoining agricultural land and nature reserves. This is mainly because alien seeds escape from these plantations to the surrounding properties, and fire hazard is subsequently increased in adjoining land. One of these problem species is *Pinus radiata*, which is (fortunately) known for its low biomass production (needle fall) levels, and minor seed spreading potential. This is in contrast to species such as *Pinus pinaster*, which was also intensively planted in plantations in the past, and today forms one of the most serious alien threats to fynbos in all Cape regions. However, *Pinus radiata* is also

highly susceptible to fire damage, and external fire breaks of adequate width are required on common boundaries, along public roads and where there are adjoining fynbos areas. Where plantations border fynbos, external fire breaks, burned on rotation, can provide adequate protection. As a further safety measure, provision should also be made for added fire protection in the form of a burning mosaic in adjoining fynbos areas. If fynbos is allowed to grow too old, external fire breaks may prove to be inadequate to stop wildfires. These “mosaic burning programmes” should also be adjusted after each major wildfire. Weeds within plantation block boundaries should be eradicated as described in section 6.2.1.

6.3 FIRE MANAGEMENT IN THE SOUTHERN CAPE AND TSITSIKAMMA, SOUTH AFRICA

6.3.1. Objectives and Practices on the Foothills of the Outeniqua and Tsitsikamma Mountains

During 1998–2000, this region experienced the worst wildfires in decades. Fires swept through various industrial plantations, and also burned thousands of hectares of fynbos in the mountain foothills and on the coastal plateau, causing serious loss of property and even the loss of human life. Accumulating fuel biomass levels in these areas, a long drought and lack of prescribed fire application throughout the region, have been identified as the main reasons for these disasters. During the past decade there has been a steady decline in fynbos block burning application, mainly because of lack of dedication to maintain a well-balanced

prescribed burning programme, as well as a steady loss of experienced burners in both nature conservation departments and the forestry industry. The result was that burnable (natural) fuel and unchecked weed spread caused the vegetation biomass loading to reach alarming levels. Consequently, these “fire hazard pockets” became too dangerous to prescribe-burn, and the fuels were just left unchecked; to wait for some future wildfire to erase these jungles. Prescribed burning inside plantation stands – proven to be a viable proposition (De Ronde, 1988) – was never adopted as a fuel reduction/fire protection tool, and the result was that fuel and weed levels reached such alarming, hazardous levels, that unstoppable wildfires just wiped out the core of the forestry industries’ timber supplies during these years.

The high percentage of fynbos-covered land in the region – in the mountain catchments, on the foothills and on the coastal plateau – should not only be well protected by rotationally-burned fire breaks situated along strategic lines, but pockets of very old fynbos (25 years and older) should be mapped and systematically burned, to reduce the immediate fire hazard threat. Thereafter, selective fynbos block burns should be re-introduced in tandem with areas allocated for “laissez faire” (natural fire) application, in co-operation with fynbos ecologists. Above all, prescribed burners must be trained well, in both the theory and the practice of fire application (also see Chapter 13).

The fast spreading human population in the region – particularly in the Southern Cape – is also creating serious urban interface problems, which should be identified and dealt with by the

local authorities and other involved landowners. Various fuel reduction measures will also have to be applied where required, and selective prescribed burning application may have to be re-introduced in selective areas to reduce the increased fire hazard as a result of population pressure.

The main objectives for the region should be to arrive at an integrated fire protection plan with all the important landowners and role players involved. Regional fire hazard evaluation, bufferzoning and prescribed burning programmes should be applied systematically after considering (and mapping) wildfire history, while existing serious fire hazard pockets and urban interface problems should be identified and dealt with. Thereafter a dedicated fuel and fire management programme should be applied as soon as possible at a co-ordinated scale (see Chapter 9).

6.3.2 Considering Fire Use in Weed Infested Areas

The spread of alien invaders, such as *Acacia mearnsii* and *Acacia melanoxylon*, has also developed into a serious hazard in the Southern Cape and in the Tsitsikamma, particularly along the rivers running through the plateau into the Indian Ocean. Some dedicated programmes have been introduced during the late 1990s to eradicate these exotic riverine “forests”, but it will take many years before the problem will finally be brought under control. The control of weed regeneration – particularly after exposure to wildfire – has been identified as a serious threat to the weed eradication progress (De Ronde, pers. obs.). However, systematic cutting and poisoning of

remaining stumps is still the best solution to the problem, although care must be taken to reduce slash fuels after cutting to manageable levels where possible. Follow-up pulling out of seedlings after fire application is also important.

Gleichenia polypodioides (Kystervaring) is not an exotic weed but an indigenous fern, but its spread – particularly in poorly-performing pine plantations – can be quite serious. In its natural habitat (fynbos and indigenous forest) it only becomes a problem (particularly in fynbos) if fire is excluded from such areas for too long, when these layers will overgrow and suppress other vegetation. Timely fire application will solve the problem effectively, because the species does not re-appear for more than a decade if layers are consumed by fire right down to the soil surface (De Ronde, 1988). In industrial plantations, the spread of this fern can only be effectively combated with prescribed burning application under the crown canopy, although increased stem density can also keep the weed outside stands effectively (De Ronde & Bredenkamp, 1984). Ideally, prescribed burning should be applied when infestation inside stands is still at an early stage. If allowed to spread to thick continuous layers, prescribed burning prior to tree felling, and/or slash burning after clearfelling and timber exploitation, will be the only effective way to clear these stands. If fire is not applied inside stands infested with *Gleichenia*, new tree generations will be exposed to similar problems at an increased scale.

6.3.3 Scheduling and Maintaining Prescribed Burning Programmes

Prescribed burning programmes, in fynbos as well as inside industrial plantations, should be re-introduced by *properly trained* regional fire services personnel, forest managers and nature conservators. The recent wildfire history in the Tsitsikamma and in the Southern Cape should be considered in such a plan, which must form part of an integrated fire management programme (see Chapter 9). Large areas of land that have been exposed to recent wildfires, can be used to advantage for scheduling prescribed burning programmes elsewhere, as these temporary fuel-free areas – already having been exposed to wildfires – will only require fuel reduction at a later stage.

Therafter (i) the training of prescribed burning staff, (ii) education of the public at large in making them understand why fire is being applied, and (iii) the restriction of fuel biomass in natural vegetation and industrial plantations to manageable levels based on sound ecological principles, should follow, to bring down (and maintain) fire hazard in the area to acceptable levels.

The maintenance of acceptable fuel levels in fynbos in the Outeniqua and Tsitsikamma mountains has been dealt with in previous paragraphs of this chapter, but areas covered by fynbos on the foothills and plateau – where this does not fall under nature conservation control – needs some attention. Some of these fynbos areas are situated in lower rainfall areas (particularly coastal fynbos), and may require less frequent fire use than the fynbos situated on the (higher rainfall) southerly slopes of the mountain ranges (e.g. fynbos in the Strandveld). However, burnable biomass will

here also increase steadily if fire is excluded for too long, and in these denser populated districts, fire hazard can thus present serious problems, as has been experienced during the 1998–2000 period.

Prescribed burning scheduling – as part of the integrated regional fire and fuel management programme – must also be applied in the coastal areas, which mostly fall under Regional Council Services or Municipal control. Prescribed burning requirements will have to be identified and programmed systematically throughout the Southern Cape and Tsitsikamma, and this management tool must be applied in the correct prescribed manner.

6.3.4 Fire Management in Forestry Plantations

The industrial plantations of the region have been plagued by some uneconomical tree growing on certain sites, as a result of poor soil structure and low nutrient levels, off-site species establishment and weed problems (such as *Gleichenia polypodioides*). At the time of writing, many of these plantations (particularly on the foothills of the Southern Cape) are in the process of a “restructuring phase”, and some uneconomical blocks may have to be set aside for alternative land use. Other plantations have been devastated by wildfires, and will have to be re-established with suitable species, fertilisation, silvicultural regimes and adequate weed control. Apart from maintaining fire breaks along strategic lines – as suggested in the integrated regional fire protection plan (Chapter 9) – prescribed burning should seriously be considered inside plantation stands where it can play a (selective) role in fire protection, fuel



6.1

management and weed control. Where *Gleichenia polypodioides* is still presenting problems inside plantation stands, these stands should be prescribed-burned if suitable for this kind of fire application, or burned with the slash after clearfelling, before re-establishment (De Ronde, 1988). Species such as *Pinus elliottii* and *Pinus pinaster* are suitable for this kind of fire treatment at early stand age, and may even have to be established for this purpose along vulnerable fire protection lines (De Ronde, 1988; De Ronde & Masson, 1998).

External fire break systems alone cannot provide adequate fire protection, and many existing protection systems will have to be re-planned because they are either wrongly placed in the landscape or have inadequate specifications (De Ronde, 1998). However, at the time of writing, these inefficiencies in fire protection measures in the region still have to be dealt with. Forestry companies should take the initiative in these improvement programmes, and start investigating improvement of existing fire break systems within the land under their control.

The use of prescribed burning on external boundaries – in fynbos or inside plantation stands

Figure 6.1. Application of a back fire in mature *Pinus elliottii* infested with *Gleichenia polypodioides*, in the Southern Cape.

– is a viable option for fire break preparation, but should be considered with other options, such as incorporating indigenous forests, ploughing of fire breaks on uniform terrain and slash burning in stands that have to be incorporated into major fire break (or bufferzone) systems. Slash burning after clearfelling has been identified as a suitable management tool to reduce high slash levels and to facilitate re-establishment after timber exploitation. It has been shown to produce improved tree growth on certain sites because of the “ash-bed effect”, particularly on phosphate-poor, clayey, duplex soils in the Tsitsikamma (De Ronde & Zwolinski, 2000).

6.4 FIRE MANAGEMENT IN THE EASTERN CAPE, DRAKENSBURG MOUNTAINS AND ON THE SOUTHERN AFRICAN HIGHVELD

6.4.1 Objectives and Practices in Montane Grasslands

The objectives of burning in montane grasslands depend on the land use. In this region the main land use types are commercial agriculture, subsistence agriculture and conservation. Protected montane grasslands catchment areas are managed primarily for the conservation of water resources, biodiversity and the preservation of the soil mantle. Managers of these areas aim to maintain the ecosystems in their natural state and conserve their genetic resource and diversity. Since sourveld areas do not naturally support large numbers of grazers, removal of top-growth by grazing alone is minimal, except in reserves where there are introductions of non-naturally occurring animals.

Fire is therefore the only practical means of managing these areas and is consequently widely used to achieve the major aims.

In commercial agricultural areas fire is used to maintain the composition and vigour of the grass sward to enhance animal production. The main objectives of burning grazed grassland are to:

- Burn off unpalatable growth left over from previous seasons to provide nutritious regrowth for livestock.
- Maintain the vigour, density and cover of palatable perennial grasses.
- Control the encroachment of undesirable plants in the veld.
- Reduce the extent of patch grazing.
- Protect the rangeland (and farm) from wildfires and accidental fires (Morris, 1998).

In subsistence agricultural areas fire is used to burn off unpalatable growth left over from previous seasons, to stimulate growth during those months when there is little forage available and to protect homesteads from wildfires.

Rangeland in agricultural areas is normally grazed during the summer so that the rate of accumulation of top-growth through the season and from one season to the next is relatively slow. Frequent burning should not therefore be necessary. It is, however, common practice for many farmers to burn grassland annually, irrespective of the amount of ungrazed material, which remains at the end of the season. This practice of grazing is commonly adopted because the regrowth of burned rangeland is more nutritious in spring than

unburned rangeland, largely because the new season's growth is not contaminated by low-quality residual material from previous seasons. The new growth is reported to have a higher nitrogen and mineral content than unburned grass in the early spring (Mes, 1958; Tainton et al., 1977), although this difference disappears as the season progresses. Animals therefore individually perform better in spring on burned than on unburned grassland, but it should be borne in mind that burning materially reduces the yield in the summer immediately following the burn. Out-of-season burning, to provide green feed for livestock when it does not occur naturally, is strongly discouraged.

6.4.2 Fire Regime, Fire Frequency and Season of Burn in Montane Grasslands

Fire regimes for montane grassland are determined principally by climate and available fuel. In general, the grassland fire regime is one of regular fires occurring mainly during late autumn, winter and spring (Edwards, 1984). Fire regimes affect the tiller initiation of individual grass species which, in turn, affect the production of grass forage. Grasses that increase with regular burning and are abundant in good grassland but decrease when it is over-utilised or under-utilised, are called "Decreasers" (Van Wyk & Van Oudtshoorn, 1999). These are generally highly palatable species such as *Themeda triandra*. "Increaser" species such as *Harpechloa falx* are usually unpalatable and can grow with an infrequent fire regime. The high rates of tiller initiation and limited tiller mortality of Decreaser species in regularly winter- or spring-burned grassland is attributed to the fact

that their shoot apices remain close to the surface at this time (Everson et al., 1988a). However, burning in summer when shoot apices were elevated had a catastrophic effect on tiller survival (< 6%) because it destroyed the apical meristem. The production of lateral tillers by *Themeda triandra* following defoliation is only prolific when defoliation occurs during the dormant season, indicating that *Themeda triandra* is adapted primarily to defoliation by fire and only moderately adapted to herbivory (Stuart-Hill & Mentis, 1982).

Absence of fire is detrimental to grassland. The vegetation becomes dense and moribund and provides a less suitable habitat for wild animals. Fires, which inevitably occur, are more severe than they would otherwise have been. The inability of Decreaser species to survive in fire exclusion areas in montane grassland, is a result of a reduction in tiller initiation in response to reduced light beneath the dense canopy. Decreased irradiance (< 30% full sunlight) eliminated *Heteropogon contortus* and *Trachypogon spicatus*, depressed tiller initiation in *Themeda triandra*, *Tristachya leucothrix* and *Alloteropsis semialata*, but had only a slight effect on the Increaser I species *Harpechloa falx* (Everson et al., 1988a). Grassland protected from fire for 16 years, and then burned, showed a 42% decrease in range condition. A corresponding reduction of canopy cover (40%) resulted in increased runoff and erosion (Everson et al., 1989). The absence of fire also results in a decrease in the vigour of plants. This is due to a decrease in light intensity at the base of the plant through the continual accumulation of dead material, which in turn results in a reduced rate

of tillering (Everson et al., 1988a). Regular burning is therefore essential for stimulating vegetative reproduction and reducing fire hazard by keeping fuel loads low. Rapid fuel accumulation, experienced in most grasslands, makes annual burning possible.

The proportional species composition of grasses varies according to frequency of burning. For example, *Themeda triandra*, *Heteropogon contortus* and *Trachypogon spicatus* increase in the sward with regular burning in Highland Sourveld, while *Tristachya leucothrix*, *Alloteropsis semialata* and *Harpechloa falx* decrease (Everson & Tainton, 1984). The reasons for such differential responses to fire are elucidated in demographic studies (Everson et al., 1985). The results reveal some interesting generalities in the population dynamics of the perennial grasses studied (*T. triandra*, *H. contortus*, *T. spicatus*, *T. leucothrix*, and *H. falx*). These include:

- In all species studied, the majority of tillers remained vegetative until death, suggesting that flowering is of minimal importance for their propagation.
- Shoot apices remained close to the soil surface, enabling all species to survive frequent defoliation.
- Recruitment of secondary tillers was stimulated by regular burning. Annual burning produced on average more secondary tillers per primary tiller than biennial spring burning.
- All species exhibited smooth survivorship curves, suggesting that dramatic fluctuations in climate and severe defoliation, as by fire, have little impact on mortality.
- A biennial burning regime would maintain the most important grass species at present levels of abundance in the KwaZulu-Natal Drakensberg.

The season in which the veld is burned remains a matter of controversy in many areas, largely because the objectives are often in dispute. The official consensus is that veld burning in these areas can be justified only as a means of removing low-quality residual material from the sward. In practice, however, burning is often used to stimulate out of season growth, and it is here that disagreement frequently arises. If the sole objective of burning is to remove low-quality material from the sward, then burning should be so timed that the grass sward is able to recover a leaf canopy in the shortest possible time. It is recognised that burning any time during the period when the plant are dormant (i.e. not actively growing) will have little long-term negative effect on the vigour, composition, cover and productivity of the sward (Morris, 1998). Recommendations are therefore based on the physiological state of the plant at the time of burn rather than the season or time of year. Burning should take place as close as possible to the start of spring growth period to ensure rapid regrowth and to minimise the period during which the soil surface is exposed to the erosive forces of wind and water.

In practice, however, it may be difficult to define the optimum burning time precisely, especially during those seasons in which the first "effective" spring rains are preceded by small quantities of rain, which – while they do not stimulate rapid spring growth – do initiate some growth.

6.2



Hence when the first “effective” rains eventually do fall, the grass is already growing and may be badly damaged by a burn. Also, it is necessary to appreciate that the farmer often needs to plan the burning programme well in advance and it may not be possible to base the timing of the programme on an unpredictable event such as the first spring rain. To overcome this problem, it is recommended that veld burning should be allowed earlier in the dormant season preceding the expected commencement of the growing season.

In practice, two factors play an important part in the farmer’s decision on when to burn rangeland in this vegetation type. Firstly, there are farmers who burn all their rangeland every year but have

inadequate alternative reserves of fodder to carry their animals through the late-winter and early-spring period. These farmers usually burn part of their rangeland with the spring rains and delay burning the remainder until the burned areas have recovered sufficiently to carry their stock. Hence, at least part of their rangeland is burned well after growth has commenced, to the extreme detriment of the rangeland. The obvious solutions to this problem are either to accumulate greater reserves of fodder to carry the animals through the period of rangeland recovery after burning, or better still, to refrain from burning all of the rangeland every year. This latter solution is generally recommended and can be achieved by preparing specific rangeland areas for late-winter

Figure 6.2. Experimental burn conducted in low-profile montane grassland (Photo: T.M. Everson).

grazing in the previous summer. Some rangeland should be grazed down evenly in mid-to-late summer, and the aftermath growth accumulated for use during the critical period in the early spring. These areas should then not require burning until the following season at the earliest.

The second problem which arises is caused by the tendency of farmers to use fire as a means of stimulating out-of-season growth. The flush of green growth in early August (after a July burn) or in April or May (after an autumn burn in March) is a very valuable source of fodder when no other good quality fodder reserves are available (Hardy & Camp, 1997). The autumn burn is associated with long periods of complete rest from burning. Such long rest periods are required in order to accumulate sufficient dry material to allow for burning at this time of year, and this practice is itself detrimental to the cover and composition of these fire climax grasslands. Many of the more preferred (decreaser) species cannot tolerate long periods of resting, so they are in time replaced by inferior (increaser) species. Fortunately, this system is no longer widely used. However, winter burning (June/July) for an enforced flush of growth in early August is still a popular management practice. Research has shown, however, that Highland Sourveld does not make appreciable growth before reasonably good spring rains. Therefore veld, which is burned early (June or July), recovers to an acceptable grazing stage no earlier (and indeed no later) than rangeland, which is burned in August, or in early September. Rangeland, which is deliberately burned early in order to provide grazing before these spring rains, is often grazed extremely heavily (and often continuously),

before it has made much regrowth. Such early grazing has a dramatic effect on the vigour of the grasses. Continued removal of the young leaf material will undoubtedly have an even greater decrease effect on seasonal production. The ability of the fire climax species to resist invasion by pioneer species will consequently be reduced, and deterioration in species composition is certain to follow. Many land owners argue that, although this enforced early season flush of growth provides relatively little grazeable material, this material does come at a critical time and it is extremely nutritious. They are therefore prepared to sacrifice the overall yield of the grass sward in order to have this material available for grazing in the early season. It is doubtful whether this argument can be justified economically, even in the short term, particularly with the current high cost of agricultural land. In the long term, this cannot be justified on either economic or on biological grounds, because of the deterioration in veld condition which follows such a practice.

Controlled burning practices in the "highveld" grasslands vary throughout the area and seem to depend on local perceptions, livestock farming activities, proximity to afforested areas and climate (Kirkman, pers. comm.). The burning practices can be divided into dormant season (or spring) burns and growing season (late summer or autumn burns). Livestock farming (both cattle and sheep) dominate the agricultural activities close to the escarpment, with crop farming increasing in importance and extent west of the escarpment.

Spring burning is practiced mostly by sheep farmers in the higher rainfall and altitude regions

of the escarpment. Many of these areas are burned annually, with the remainder being burned in some sort of formal or informal rotation. Very few areas are excluded from fire. The burning frequency decreases along the rainfall gradient in a westerly direction as crop farming increases, livestock farming decreases and range quality increases. Rangeland on some of the heavy, black turf-type soils occurring on the easter highveld, is seldom burned, due to inherently higher quality. Many land users are incorporating grazing, resting and burning into more formal systems, where veld is usually only burned after a full or partial growing season rest, followed by winter grazing (Kirkman, pers. comm.).

Late summer or autumn burning is practised in two parts of the highveld, namely in the Badplaas area of the escarpment and the Wakkerstroom area, straddling the escarpment of the Southern Mpumalanga Drakensberg. This is done to provide actively growing, high quality grazing for sheep lambing in autumn. The practice is sometimes combined with long rest periods to build up enough fuel for the growing season burn. Such grassland will be burned and grazed during a particular autumn and winter, and then rested for 18 months before the next burn. In some cases the grassland is not rested for this length of time, but burning in autumn is applied opportunistically, i.e. when there is enough to carry a fire (Kirkman, pers. comm.).

Only in limited situations is fire a necessary tool in the fire climax grassland areas to assist in combating encroachment by weed species. It may be used where species of macchia or fire-sensitive herbaceous plants – for example *Helichrysum*

argyrophyllum and *H. aureum* – invade. In such situations, specific programmes must be developed according to each particular situation. For *H. argyrophyllum* and *H. aureum*, for example, a single fire will usually suffice, provided the grass sward is able to offer sufficient competition during the post-burn period to reduce the capacity of the weed to recover. In other situations, however, an effective programme may require a series of burns at varying intervals. Another invader of humid fire climax grassland areas is the shrub *Leucosidea sericea* (*chi-chi bos* or *ouhout*), which – in spite of coppicing freely after a fire – can be controlled by burning initially at two-year intervals until such time as a vigorous grass sward has developed, and by then lengthening the burning interval to four years if the plant continues to pose a threat to the grassland (Trollope, 1973).

In order to provide some control over burning practices in the fire/grazing grasslands of KwaZulu-Natal (where the primary objective should be that of removing unpalatable low-quality material), guidelines have been formulated for the different ecological regions. These guidelines stipulate the conditions under which rangeland may or may not be burned, and which are mandatory for all farmers in the KwaZulu-Natal region. Burning is permissible outside these guidelines only with the special permission of the local Soil Conservation Committee. The guidelines, which are currently in operation in KwaZulu-Natal, prohibit the burning of rangeland before a particular date in mid-winter, the date depending on the ecological area concerned. Thereafter, burning is permitted for a prescribed period, provided it is applied within a certain number of

days of the first effective spring rains (15 mm of rain in 24 hours), and this is followed by a period during which rangeland may be burned with or without rain. However, in each zone a terminal date is set, after which burning is again prohibited. In the Highland Sourveld, for example, no burning is permitted before 1 August. Burning is permitted during August only if it follows within three to five days of at least 15 mm of rain in 24 hours or, with the special permission of the Soil Conservation Committee, if it follows an autumn rest. During September, rangeland may be burned with or without rain, but no burning is permitted after 30 September. Control is thus in this way applied by the Soil Conservation Committee on the conditions under which rangeland can be burned, but it has been found impractical to enforce regulations governing subsequent grazing practice. Here lies the great weakness in current controlled burning regulations.

These guidelines do not specify the type of burn that should be applied, perhaps because little information is currently available on the response of grassveld to fires of different types. Trollope, working at Alice in the Eastern Cape, has, however, provided some guidelines in this respect (Trollope, 1989). He has shown that while fires, which burn with the wind as head fires, are generally more intense than those which burn against the wind (back fires), temperatures at ground level are higher in back fires than in head fires. Back fires are therefore more likely to produce temperatures in excess of the critical temperature of 95°C for a sufficient length of time (> 20 seconds) to damage the crown of the plant than are head fires (Trollope, 1989). He has shown that such damage

has a depressive effect on recovery growth and that it will result in a reduction in yield.

As a result of his experience with grassland fires, Trollope (1989) has suggested that fires should be applied as head fires. In order to further reduce the intensity of fire, grassland should be burned only when the air temperature is below 20°C and when relative humidity is above 50%. These conditions prevail mostly before 11:00 in the morning, and after 15:30 in the afternoon, and where possible burning should be restricted to these times.

6.4.3 Prescribed Burning in Montane Grassland

Prescribed burning is mainly carried out in conservation areas. The grasslands of the KwaZulu-Natal Drakensberg are fire-prone, and prescribed burning is important in the management of these areas. Accurate and standardised fire danger ratings are required by managers of such areas, so that they can decide when it is safe to burn, and when they can reasonably expect wildfires to occur.

The climate of the grassland biome is characterised by dry winters and wet summers. Grasses grow actively in summer, resulting in high fuel moisture contents. Once parts of the grasses are killed by the first winter frosts, the herbage gradually dries. This process, termed curing, is of prime importance in determining the way in which a fire reacts to the variables of fuel, weather and topography.

Burning in late spring and early summer, after active growth has commenced, causes severe damage to the grass cover and populations of *Themeda triandra* in Highland Sourveld. To

maintain the vegetation in its present condition, burning is not permitted from October onwards. The ideal burning period is late winter (August to September) while the grasses are still dormant. There is therefore a relatively short period during which managers can implement burns. The only sensible option for managers of large areas is therefore to burn earlier in the season, during early winter. Although fire hazard is high at this time, the grasses are 95% cured by June, and opportunities for safe burns do occur after light rain or snow (Everson et al., 1988b).

Grasslands burned in June (winter) green up by October, forming a protective canopy over the soil before the heavy summer rains. The soil is, however, exposed to potential wind erosion before growth starts in September. In contrast, grasslands burned in October (spring), only recover by the end of November, exposing the soil to the storms of October and November. Differences in season of burn therefore result in exposure to erosive forces at different times of the year (Everson et al., 1988b). Extension of the burning season during the period of dormancy of the grass avoids the detrimental effects of burning in the early growing season, and has improved the efficiency of the fire management programme. For example, in the Highland Sourveld areas of the Natal Drakensberg, the burning season is currently rotated between three periods:

- May (early winter)
- June – July (winter)
- August – mid-September (early spring)

This seasonal rotation is aimed at encouraging ecological resilience by ensuring that a management compartment is burned in the same period (season) once every six years (Everson, 1985). In this way no species is favoured at the expense of others. In addition, there is a phased reduction in fuel loads during the dry season, minimising the risk of wildfire.

Catchments are divided into compartments or blocks of about 1000–1500 ha, in which the appropriate burning prescriptions are applied. Compartments are separated by permanent boundaries along paths and streams or by other landscape features.

Where no natural features occur, fire breaks are used. Prescribed burns are applied when the prevailing weather conditions are suitable for achieving the aims of the particular burn. This is generally when wind speeds and temperatures are low and atmospheric humidity is high. Since these three atmospheric variables influence the rate of spread of a fire independently, it is difficult to specify their limits for prescribed burning. Fire danger rating models are therefore used to integrate all the atmospheric and plant variables (such as fuel loads and fuel moisture content) into a single burning index (Everson et al. 1988c). Prescribed burning can then be carried out safely by applying burns when the burning index is within specified limits.

6.4.4 Fire Management Regimes in Industrial Plantations

6.4.4.1 Industrial Plantations of the Eastern Cape, South Africa

Industrial plantations in this region are mainly located in pockets around Stutterheim, Ugie and in the Transkei districts. During the late 1980s more than 30 000 ha of new plantations were established in the north-eastern Cape (Elliott-Ugie-Maclear area), significantly changing the landscape and land use between the dominant Drakensberg Mountains in the north, and the Transkei in the south. As a consequence, fire management objectives had to change drastically, as these plantations and farming land now form a complex mosaic of mainly pine plantation blocks, cultivated land (mainly maize) and montane grassland, used for formal (managed) and informal (normally intensive) grazing.

With a typical dynamic grassland base, the fuels to manage at early plantation age will be typical summer rainfall grassland, as was discussed in section 6.3. However, as plantations mature, these stands first threaten these districts as a result of the increased fire hazard of the old grassland within plantation blocks and, secondly, by the external (high) fire hazard on plantation boundaries. Then – as tree crown canopy close – more fire hazard is created as yearly needle fall is added to this (already old) grassland fuel base.

Bufferzones and other fire breaks (external and internal) have to be burned yearly along strategic lines to meet the yearly wildfire threat as grassland fuels cure, and the dry winter season sets in. Integrated regional fire protection has been

introduced in some districts of the Eastern Cape, and an urgent need exists to introduce this fire protection strategy elsewhere (De Ronde, 1990), as there are serious shortcomings in the remainder of the region. All fire breaks need to be evaluated in terms of potential fire hazard, and reconstructed if necessary (see Chapter 9).

The basis of fire protection still forms the burning of grassland fire breaks after grassland curing sets in, within areas marked by tracer belts before curing starts. These burning operations have to be applied at set priorities, starting with the external protection along north-western external boundaries, the direction where most wildfires come from. In most cases, major bufferzones have been introduced along these lines, extending far inside adjoining, private, grassland where necessary. The dynamics of the plantations – and the impact this has on future fire protection requirements – also has to be classified and mapped and planned over time. This will make yearly adjustments to fire break specifications and prescribed burning possible (De Ronde, 1990). To read more about regional fire protection application, see Chapter 9.

In rural areas of the region, the impact of different grazing intensities also has to be considered for fuel management purposes. In many of the plantations bordering rural communities intensive grazing is applied to the extent that wildfire seldom originates from these lands. However, grazing intensity and regularity of grazing application needs to be monitored carefully along all the plantation boundaries, particularly in the north-west, as this will determine the degree of fire hazard during the fire season.

6.3



6.4.4.2 Industrial Plantations of KwaZulu-Natal and Mpumalanga Provinces, South Africa

These regions have a reputation for extremely strong northwesterly winds during the later part of the fire season (i.e. end August to beginning October), and a subsequent very serious fire hazard in unburned grassland and adjoining industrial plantations. For many years, wildfires have burned through thousands of hectares of Highveld forestry plantations, but with the implementation of an integrated fire protection plan and effective fuel management programmes during 1996–1998, most of these areas have experienced a significant reduction in percentage planted hectare lost in wildfires.

Very wide bufferzones (sometimes exceeding a width of 1.0 km) have been established in the region, to attempt containment of runaway grassland fires. As it was not always possible to achieve this in available grassland on external western and northern boundaries, some of these strategic lines now also include a high percentage grassland on adjoining (farming) land, main river courses, public roads and other features low in fuel levels. Prescribed burned plantation compart-

ments have also been incorporated in some of the main bufferzones, and particularly suitable for this purpose are *Pinus elliottii* stands. Where possible, even “prescribed burning chains” were formed out of strings of compartments, in the absence of other suitable land (De Ronde, 1997). Most of these compartments are today prescribed burned on a two-year rotation – 50% of the area during the first year and the remainder during the second year.

Because fuel loading is sometimes a major problem after various short rotations of *Eucalyptus* without slash management, other than stacking of slash in rows, systematic fuel reduction measures had to be incorporated in some of these stands, particularly as many of these stands are now being converted to *Pinus* spp. Forest floor accumulation problems have also been observed in some *Pinus patula* blocks at high altitude, and in these areas fuel reduction measures – other than for fire protection purposes – will also have to be considered.

Where grassland (particularly in the case of some wetlands, and along rivers) has to be burned on a two- or three-year rotation to maintain biodiversity, this can be done by burning such areas in strips or by riverside, thus still performing an important role in fire protection (De Ronde, 1997; 1998).

6.5 FIRE MANAGEMENT IN THE KRUGER NATIONAL PARK, SOUTH AFRICA

6.5.1 Background

Managers in the Kruger National Park have used fire for decades, and yet it is still one of the most controversial and least understood management

Figure 6.3. Litter accumulation in a clearfelled *Pinus patula* stand, at high altitude, in the Sabie area, Mpumalanga Province, South Africa. The spade handle illustrates the thickness of the litter stratum (Photo: C.J. Schutz).

practices. Despite a long history of fire research in the Kruger National Park, opinions are divided on the approach that should be adopted to fire management. This chapter reviews what is known about fire in southern African savannas, with specific reference to the situation in the Kruger National Park. It provides an overview of the history of fire and fire management in the Park, and the evidence for its effects on the vegetation as well as the ecology of the Park. The options for fire management are described and compared to approaches adopted in other important conservation areas of the world. In line with the theme of this volume, we have focussed on the highly

variable and heterogenous nature of fire regimes and their role as a key contributor to the dynamic character of savanna ecosystems in the Kruger National Park.

6.5.2 A History of Fire Research and Fire in the Kruger National Park

6.5.2.1 Fire Management

The various approaches to fire management in the Kruger National Park over the past 75 years have reflected the evolution of an understanding of the role of fire in savanna ecosystems. Early ideas were formed around equilibrium theory – fire was regarded first as something to be avoided,

Table 6.1. Different fire management policies applied in the Kruger National Park since its proclamation in 1926 (summarised from Van Wilgen et al., 1990; Van Wilgen et al., 1998).

Dates	Approach to fire management	Rationale for approach
1926 – 1947	Occasional and limited burning	Provision of green grazing for wildlife
1948 – 1956	All prescribed burning stopped and firebreaks established to assist in the control of wildfires	Concern about the perceived negative effects of fire
1957 – 1974	Formal system of prescribed burning once every three years in spring on fixed management areas (“burning blocks”)	Necessity of fire in the maintenance of ecosystem health recognised
1975 – 1992	As above, but allowing for longer periods between fires in drier areas, with season varied between late winter, mid-summer and autumn	Application of fires over a longer period spread the workload more evenly and ensured better utilisation of post-fire grazing
1992 – present	Lightning fires combined with suppression of anthropogenic fires	Simulation of “natural” conditions under which the biota evolved

and was later applied at a fixed return period, when it was realised that fire was an integral part of the system. However, with the development of non-equilibrium theories of savanna dynamics (Mentis & Bailey, 1990; Walker, 1989), policy and practice in fire management have shifted towards burning under diverse rather than fixed conditions (Table 6.1).

The fire management of the Kruger National Park was characterised by fixed-cycle prescribed burning for a long period – 36 years between 1956 and 1992 (Table 6.1). A number of concerns were raised about the putative effects of this policy, and these led to a change in policy to a lightning fire approach (Van Wilgen et al., 1998; Biggs & Potgieter, 1999). The concerns included:

- The observation that a dominance of grass species characteristic overgrazing (increaser II species) was a result of “excessively frequent burning” in combination with the over-provision of artificial drinking points (Trollope et al., 1995);
- The observation that the cover and density of large trees had declined as a result of regular, short-interval prescribed burning (preventing the recruitment of trees into larger, fire-tolerant age classes), combined with increased utilisation of large trees by elephants, with subsequent mortality (Trollope et al., 1998; Eckhardt et al., 2000);
- The practice of “ring-burning” associated with prescribed burning. This refers to the process where fires are ignited around the periphery of management blocks and allowed to burn towards the centre. More natural fires, for

example, those fires that are associated with lightning strikes, would spread out in all directions from a point, allowing the fire to develop a range of intensities as it spread. Ring-burning can prevent animals from escaping from fires, and also results in a disproportionately large area burning as a high-intensity head fire (an effect magnified by the fact that these fires are carried out during the day, and seldom at night).

- The lack of variation associated with burning on a fixed cycle. This includes a lack of occasional longer periods between fires, or varying the size of fires, on the assumption that such variation will promote the conservation of biodiversity.

The above concerns led to a debate on the role that lightning ignitions should play in producing a more variable fire regime based on point ignitions. Originally, it was suggested that lightning should play a more important role in the fire regime of the park, and not necessarily that it should dominate or completely replace prescribed burning. However, a policy of “natural” fires was adopted by a majority of park managers who supported the notion of wilderness ecosystem management (Biggs & Potgieter, 1999). This policy calls for allowing all lightning-ignited fires to burn freely, while at the same time preventing, suppressing or containing all other fires of human origin. The basic philosophy behind this approach was that lightning fires should produce the same patterns of frequency, season and intensity that characterised the regime under which the park’s biota evolved. As such, it should be in line with the national park’s

mission statement, which calls for the maintenance of biodiversity “in all its natural facets and fluxes”. The alternative philosophy is that anthropogenic fire has been a factor of some antiquity in the ecosystems of southern Africa (Hall, 1984). A controlled burning system was therefore developed for the Kruger Park to maximise species diversity by taking into account the standing crop and botanical composition of the grass sward (Trollope et al., 1995). The decision to change to a lightning-driven policy was taken by managers, and this could not be maintained as it was impossible to prevent anthropogenic fires. The burning policy was later reviewed when severe fires caused by Mozambique refugees burnt out 75% of the Kruger Park and tragic loss of life occurred. The result of this was the initiation of an Integrated Fire Management Plan which recognises both the role of lightning fires and permits application of controlled burns based on range condition criteria.

6.5.2.2 Fire History

The fire regimes that characterised the Kruger National Park before the early 20th century are a matter of speculation. Prior to the proclamation of the Sabie Game Reserve in 1898, the area that is now the Kruger National Park was settled, first by San hunter-gatherers, and later by migrating tribes from the north. Existing evidence shows that the Kruger National Park was settled since at least the 4th century AD by Iron Age communities (Plug, 1989). The environment was not suitable for agriculture or herding on a large scale, and it appears that the main form of subsistence was from hunting (Plug, 1987). Undoubtedly, the

indigenous peoples used fire, and this must have had an influence on the vegetation and habitats of the area.

The more recent fire history of the Kruger National Park has been analysed from comprehensive records that spanned most of the second half of the 20th century (Van Wilgen et al., 2000). This analysis showed that fires covering 16.79 million ha occurred between 1941 and 1996 (16% of the area burning each year on average). Of this area, 5.15 million ha was burned between 1941 and 1957, when limited prescribed burning and protection from fire took place. Between 1957 and 1991, 2213 prescribed burns covering 5.1 million ha (46.3% of the 10.98 million ha burnt during that period) were carried out. Lightning fires burnt 2.5 million ha between 1957 and 1996, or 21.6% of the area burnt during that period. The mean fire return period was 4.5 years, with intervals between fires from 1 to 34 years. The distribution around the mean was not symmetrical and the median interval was 3.1 years. Some areas burned more often than others, and the mean fire return periods ranged from 2.7 to 7.1 years in the 11 major land systems of the park (Van Wilgen et al., 2000). Mean annual rainfall had a significant effect on fire return periods, with mean fire return periods of 3.5 years in areas receiving more than an average of 700 mm, compared to return periods of between 5.0 and 5.3 years in areas receiving less than 700 mm annually.

The fire history of the Kruger National Park is a product of both the fire management efforts, as well as of other factors that influence the occurrence of fire. For example, despite management intentions,

some areas are burnt by wildfires, while at other times scheduled prescribed burns could not be carried out (for example following years of low rainfall when grass productivity would have been low and herbivores would have consumed most of the grass biomass). Thus, only about half of the fires that burned between 1957 and 1992 (52% including firebreak burns) were planned burns resulting from formal fire management – the rest were unplanned fires. The occurrence of fire was strongly correlated with grass biomass, which in turn resulted from the amount of rainfall in the previous season (see Table 6.2 for fire return periods in wet and dry climatic cycles). This relationship may have been as important in determining whether an area will burn, and how

much of it will burn, as the reigning fire management policy.

6.5.3 Options for Managers

Following the decision to abandon the system of regular prescribed burning in fixed areas, managers in the Kruger National Park have considered a number of alternative approaches. The intention was to manage the majority of the park by means of the lightning fire approach, while at the same time running a trial of the other management options (excluding the option of regular, block-based prescribed burning).

However, problems with the lightning system have forced a rethink of the policy. The problems included the fact that the majority of the area that

Table 6.2. Features of the fire regime in the Kruger National Park between 1941 and 1996 (data from Trollope, 1993; Van Wilgen et al., 2000).

Feature of fire regime	Wet climatic cycle (1971–1980)	Dry climatic cycle (1983–1992)	All years
Mean annual rainfall for period (mm)	638	450	534
Extent of fires (km ²)	44 149	20 834	167 947
Frequency (mean fire return period in years)	4.3	9.1	4.5
Season	No data	No data	Fires in all months, but most (80%) from June to November, peak in September
Intensity	No data	No data	Intensities range from < 100 to > 6000 kW m ⁻¹ , relative distribution of intensities not known



burnt in the first eight years that the policy was in force, was burned by non-lightning fires (fires started by lightning burned only 533 020 out of 1 688 234 ha, or 32%). If one excludes 1996, when lightning fires burned 292 812 ha (65% of the area burned that year), then the proportion of the area burnt in lightning fires drops to 19%, which means that the goals of allowing a lightning-dominated fire regime to develop are simply not being met. This has also meant that managers have had to spend a lot of time and effort containing wildfires. In response, managers are (at the time of writing) considering an integrated approach that will combine elements of patch mosaic burning with the lightning fire approach (Table 6.3). This will mean that many of the non-planned ignitions

can be left to burn (negating the need to contain all of the fires), while at the same time allowing managers some form of control through applying prescribed burns in areas where the condition of the herbaceous grass layer indicate that fire is necessary.

The above dilemma is understandable in view of the difficulties that managers face when they are asked to manage very dynamic systems that are always in flux. Management is goal-oriented, and in the past managers in the Kruger National Park have used fire to drive the system towards a desired stable state. With the more recent recognition that savanna systems are both extremely dynamic and reliant on variation, goals need to change towards those that describe the desired

Figure 6.4. Wildfire burning in savanna grassland in the Kruger National Park, South Africa (Photo W.S.W. Trollope).

Table 6.3. Salient features of five approaches to fire management in the Kruger National Park.

	Fixed Rotational Burning	Lightning Fires	Patch Burning	Range Condition Burning	Integrated Approach
<i>Basic philosophy</i>	Regular fire is necessary to improve the quality of grass forage	Lightning fires should produce the same fire regime as the one under which the park's biota evolved	Application should result in a heterogenous vegetation structure at a fine scale, and thereby maximise biodiversity	Given that the desired composition, structure and dynamics of the vegetation are known, a fire regime can be selected to produce that vegetation	Combines the features of lightning range condition patch mosaic burning systems
<i>Application</i>	Fires are ignited on fixed areas on a fixed cycle	Any fire ignited by lightning is allowed to burn freely, and all other fires are extinguished or contained	Random point ignitions spread over the fire season until a target area (based on early dry season grass biomass) is achieved	Areas are burnt when sufficient fuel is present and when grass species composition meets certain criteria	Point ignitions are applied and permitted in areas selected according to range condition criteria until a target area is reached which only lightning ignitions are allowed to spread
<i>Problems</i>	Lack of variation; negative effects on the vegetation; and problems associated with "ringburning"	In practice, most fires are ignited by non-lightning sources, and managers have to put a great deal of effort into fire control	Concerns over safety aspects	Perceptions that the approach is based on agricultural principles and is inappropriate for a conservation area	Untested as yet
<i>Source</i>	Van Wilgen et al. (1990)	Trollope et al. (1995)	Brockett et al. (2001)	Trollope et al. (1995)	Unpublished reports

ranges of flux rather than fixed states. Fire, herbivory and cycles in rainfall are the major drivers responsible for the dynamics of savannas; of these, fire and herbivory are the two that can be influenced by managers. Because of a history of stable-state thinking, ideas around “appropriate” fire regimes tended to descriptions of fixed return periods and seasons. The new goals of maintaining biodiversity “in all its natural facets and fluxes” require fire management goals to be framed in terms of a range of return periods and seasons. This is especially true where fire is being used as a surrogate measure for assessing the ultimate goal of biodiversity, as suggested by Van Wilgen et al. (1998). Goals could also be framed as a range of vegetation conditions (where fire is being used in an attempt to achieve such conditions).

Although the different approaches outlined in Table 6.3 arise from different philosophies, they may, in reality, not differ in the actual fire patterns that they produce. The likelihood of this is increased by the fact that each approach will be affected to some degree by unplanned fires. Another source of uncertainty is that ecologists cannot accurately predict the biological consequences of these patterns on all elements of the biota. Despite the importance of fire in the dynamics of savanna ecosystems, demographic studies of savanna trees and grasses have been neglected (Bond & Van Wilgen, 1996; Scholes, 1997). In fact, for many years, ecologists working in savannas did not regard them as a separate biome – rather savannas tended to be viewed as a special case of grassland or forest (Scholes & Walker, 1993). Pasture scientists studied the grasses and dealt with problems of “bush encroachment” (e.g. Trollope,

1982); foresters dealt with tree species for timber production (e.g. Geldenhuys, 1977). More recent studies have concentrated on determinants of savannas, such as water, herbivory and nutrients (Scholes & Walker, 1993). Despite the significant advances that have been made in understanding the determinants of savannas, therefore, we are poorly equipped to predict the impacts of fires in combination with other factors, even on key plant or animal species.

If ecologists are to have an influence on the direction of conservation management, appropriate responses to the lack of predictive ability have to be developed. It should be recognised that conservation management is goal-oriented, and managers seek to manipulate (either passively or actively) the forces that alter the nature of the landscape mosaic (Rogers, 1997). In the case of fire management in the Kruger National Park, the goal is to conserve biodiversity through the application of an appropriate fire regime. Because of the difficulties inherent in predicting the effects of fire on all facets of biodiversity, Van Wilgen et al. (1998) have suggested that fire patterns can be used as surrogate measures of biodiversity. For argument’s sake, if it was postulated that each of the management systems proposed (Table 6.1) would be able to conserve biodiversity equally well, this could be tested by monitoring both the fire patterns that establish themselves (the surrogate measures) and the responses of various plant and animal populations. Under the new management policy in the Kruger National Park, each of the biotic elements that are monitored would exist within an acceptable range of states, which, if exceeded, would prompt an assessment of the

causal factors. Provided fire patterns are also monitored, the changes can be interpreted against the background of a known fire history. This could lead to a change in fire management, or to the initiation of a research project to develop further understanding of the response – a “response research framework” (Rogers, 1997), or both. In the meantime, the fire patterns themselves can form goals against which managers can assess progress towards the conservation of diversity (Van Wilgen et al., 1998).

Concerns about incorporating variability into prescribed fire regimes are not unique to southern African savannas. Gill and McCarthy (1998) examined various sources of evidence that could be used to determine variation appropriate to the conservation of biodiversity while minimising the chances of economically destructive fires in Australian ecosystems. They suggest that primary juvenile periods of certain plants (especially of “serotinous seeders”) and non-breeding periods of birds (especially poorly-dispersed species) could be used to set extreme lower limits for fire intervals, whereas longevity of plant species which usually only reproduce after fire could be used to set the extreme upper limits. Modelling of the behaviour of selected plant and animal species may be used to set “optimal” mean intervals, and historical fire-interval data might be useful for determining the variation about the mean fire interval. Gill and McCarthy’s suggested approach is similar to the trends currently developing in the Kruger National Park, and they have also highlighted the need for research on the life history traits of indicator species, and the keeping of good records of fires and the areas they cover

against which to interpret the responses of the biota.

6.6 NGORONGORO, TANZANIA

Recent studies in the Ngorongoro Crater in Tanzania have suggested that the re-introduction of a controlled burning programme could be an ecologically viable solution to the high tick populations that infest areas of grassland in the Crater with excessively high grass fuel loads. A significant number of buffalo (1000), wildebeest (250) and zebra (100) died in this area, apparently mainly due to nutritional stress resulting from the severe drought from May to November 2000. However, in the case of the buffalo mortalities, high tick burdens and tick-borne protozoal diseases were probably also involved (Morkel, 2001). These animal mortalities, particularly of the rhinos and lions, are viewed in a very serious light in Tanzania because the Serengeti ecosystem, comprising the Ngorongoro Crater and the Serengeti National Park, is one the most ecologically significant and important wildlife areas in Africa and forms the backbone of the highly lucrative eco-tourism industry in Tanzania.

A classification of grass species, into either “decreasers” or “increasers”, was applied by Trollope and Trollope (1995). This classification of grasses is very useful for range management and refers to the reaction of different grass species to a grazing gradient ranging from high intensity grazing to low intensity grazing namely:

- *Decreaser Grass Species:* Grass and herbaceous species, which decrease with low or high intensity grazing.

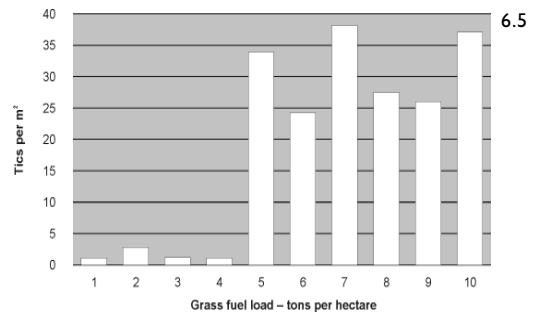
- *Increaser I grass species*: Grass and herbaceous species, which increase with low intensity grazing.
- *Increaser II grass species*: Grass and herbaceous species, which increase with high intensity grazing.

The subjective identification of the dominant decreaser and increaser grass species proved to be scientifically adequate for the preliminary description of the condition of the rangelands in the Ngorongoro Crater.

Trollope and Trollope (2001) found that high tick populations were particularly common if the grassland exceeded 4000 kg/ha. These results are illustrated in Figure 6.5. Relating these results to the condition of the grass sward in the Ngorongoro Crater, the dramatic increase in the incidence of ticks occurred when the grass was in a mature and overgrown, i.e. moribund, condition.

The following general conclusions can be drawn from the results obtained from the investigation into the relationship between range condition and the incidence of ticks in the Ngorongoro Crater. Firstly it must be emphasised though, that these data were obtained over a very short period of time (five days), and therefore must be regarded as being preliminary findings that need to be confirmed if possible with a more in depth investigation.

- There was a marked increase in the incidence of ticks when the grass sward exceeded 4000 kg/ha, i.e. when the grass sward became excessively overgrown and moribund.



- Mature stands of grassland, dominated by *Chloris gayana* (Rhodes grass) in full seed, provided ideal habitat for excessively high densities of ticks.
- The areas frequented by buffaloes had high tick loads in comparison to areas utilised by other gregarious wildlife species like zebras, wildebeest and Thompson's gazelle.
- The standing crop of grass in areas grazed by buffaloes was generally greater than 4000 kg/ha compared to those utilised by zebras, wildebeest and Thompson's gazelle, which were generally less than 4000 kg/ha.
- Areas frequented by domestic livestock, particularly cattle, outside the Ngorongoro Crater had a significantly lower incidence of ticks. These areas were generally not in an overgrown and moribund condition and the standing crop of grass usually did not exceed 3000–4000 kg/ha. Discussions with Masai pastoralists indicated that these rangelands were maintained in this condition by regular burning, specifically to control ticks and provide nutritious grazing.
- Mature and moribund stands of grassland exceeding 4000 kg/ha were of low nutritional

Figure 6.5. The relationship between the standing crop of grass and the density of ticks recorded in the Ngorongoro Crater and environs in Tanzania (Trollope & Trollope, 2001).

value for grazing animals compared to areas with less than 4000 kg/ha.

- A comparison of the condition of the rangelands and the incidence of ticks in the Crater and the surrounding areas outside the Crater leads to the conclusion that the withdrawal of regular burning in the Crater since the early 1970s has contributed to both the excessive accumulation of moribund grass as well as the consequent high incidence of ticks.

Based on the conclusions outlined above, it has been strongly recommended that a controlled burning programme be re-introduced into the Ngorongoro Crater as a means of reducing the high incidence of ticks in the moribund grasslands. Burning could reduce the excessive standing crop of grass, thereby altering the microclimate and making it less suitable for ticks. It could also have the added advantage of significantly improving the nutritional status of the grass sward. It has also been recommended that – in conjunction with the burning programme – a range monitoring programme be introduced to provide the objective means of managing the burning programme. Details of these two recommendations will be dealt with separately.

6.6.1 Controlled Burning Programme

The following guidelines and criteria are recommended for the application of controlled burning in the Crater.

6.6.1.1 Selection of Areas to be Burned

An area should be considered for burning only if

it is dominated by decreaser and/or increaser I grass species, and if it is in a moribund condition as indicated by a grass fuel load of > 4000 kg/ha.

6.6.1.2 Size of Area to be Burned

Considering the highly variable, mean annual rainfall of +550 mm in the Crater, it is recommended that not more than 10% of the Crater be burned at any one time. Assuming that the total area of the Crater is 25 000 ha, the maximum area to be burned should therefore not exceed approximately 2500 ha during any one year. This will result in a theoretical maximum burning frequency of once in ten years, for any one area. However, the actual burning frequency will be determined by the accumulated grass fuel load resulting from the prevailing rainfall and the intensity of grazing. Finally, the minimum area burned should not be less than 500 ha in order to prevent overgrazing of the burned rangeland.

6.6.2 Fire Regime

The following fire regime is recommended for the application of the controlled burns.

6.6.2.1 Type of Fire

The controlled burns must be applied as surface head fires burning with the wind, in order to minimise the detrimental effect of the fire on the grass sward. This can be achieved by ringfiring the area to be burned once the initial precautionary back fires have been initiated, using the existing network of tourist roads as fire breaks as far as possible.

6.6.2.1 Fire Intensity

A cool fire is recommended for the application of the controlled burns. This can be achieved by burning when the air temperature and relative humidity are $< 20^{\circ}\text{C}$ and $> 50\%$ respectively. This can be achieved by burning during the late afternoon, and allowing it to burn into the night, when atmospheric conditions are cool. Observations made in 1995 showed that the Masai pastoralists in the areas surrounding the Crater use this strategy to great benefit when burning the rangelands. Burning immediately after rain is another option for reducing the intensity of the fire provided the grass is still dormant.

6.6.2.3 Season of Burning

Controlled burning must be applied when the grass sward is dormant, just before or immediately after the first rains in October/November, depending upon whichever time is more practical.

6.6.2.4 Frequency of Burning

The frequency of burning will be determined by the rate of accumulation of unpalatable and moribund grass material ($> 4000 \text{ kg/ha}$). This in turn will be influenced by the amount of rainfall and the intensity of grazing.

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7

FIRE MANAGEMENT IN RURAL AREAS AND INDUSTRIAL FORESTRY PLANTATIONS

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7.1 INTRODUCTION

Fire management in the communal rangelands of South Africa is a dynamic and challenging process. The wide spread of homesteads of rural communities throughout the landscape, the lack of fire fighting equipment, poor institutional support and poor access through lack of roads are major constraints in fire management. In this chapter we will look at historical, social and institutional issues that have to be considered, before arriving at recommended fire use. Another region in Africa, south of the Sahara, where specific fire use is required to maintain biodiversity, while simultaneously sustainable grazing has to be provided, is the savanna grasslands of Uganda. This issue will also be elaborated on in this chapter.

One of the industries where fire plays an extremely important role is the forestry industry in southern Africa, where fire has the potential

to destroy large areas with vast timber crops. Because the even-aged industrial plantations are established in natural ecosystems, which require fire to maintain biodiversity, and because the tree species originate from equally fire dependent ecosystems, the role of fire within the plantation environment should never be under-estimated. The second part of this chapter will deal with the use of fire in forestry plantations for specific purposes.

7.2 REGULATING FIRE APPLICATION AND GRAZING IN RURAL AREAS

7.2.1 Grazing and Fire in Rural Areas of Montane Grasslands of South Africa

A large part of the KwaZulu-Natal Drakensberg area comprises communal rangelands. Communal rangelands are defined as “those areas where agriculture is largely subsistence-based and where

rangelands are generally communally-owned and managed”, as opposed to private or individual ownership. The main objective of livestock owners in these areas is to keep animals for draught, insurance, security, social exchange, milk and meat production (Lawry, 1986; Scoones, 1992). These objectives therefore differ from those of commercial livestock farmers, which are mainly meat and milk production, for economic returns. Nevertheless, grazing and fire play an integral role in the veld production of both systems.

7.2.1.1 Historical Issues

Traditionally, the response of African pastoral societies to variable forage availability was to retain a high degree of mobility (nomadic pastoralism). There is evidence that by the early 18th century regular burning was practised by rural people to stimulate a green flush of new growth to improve grazing and to aid hunting (Bryant, 1929). Increased population pressure and political changes have contributed to the breakdown of this type of pastoralism.

With the implementation of the 1913 Land Act, rural people were settled into “homelands” and forced to subsist either on marginal agricultural land or on high potential land, which required large amounts of capital and an in-depth knowledge of intensive production systems in order to use it effectively. There was no organised fire management plan in communal areas, and individuals burned on an *ad hoc* basis to improve veld utilisation. Between 1914 and 1930 livestock numbers increased beyond the carrying capacity of the rangelands, and signs of over-utilisation

became evident. During 1932, a Commission of Enquiry into the Agricultural Economy of “Bantu Reserves” warned that accelerated soil erosion through over-grazing was turning developing areas into deserts. This led to the proclamation of “Betterment” Areas in 1939.

Many communal areas in the Drakensberg were Betterment-planned in the 1950s. Planners who sought to impose a “scientific” resource management regime, divided communal areas into three main resource areas. Each resource area had unique tenure arrangements and rules (Von Maltitz, 1998).

- *The homestead area*

Under this regime, the traditional settlement pattern of scattered homesteads was replaced by villages. Each family was allocated land on which to build their homestead. Tenure for this land was generally secure. It was common for this area to be fenced and used for kraaling livestock, keeping poultry and growing fruit and vegetables.

- *The fields*

Here households had usage rights to specific fields. Tenure of this land was relatively secure and was allocated by the “tribal authority”. Rights to exclusive use of the fields was reserved for the summer months. In winter, the fields were used for communal grazing. All maize stalks (stover) were considered to be part of the communal winter grazing resource. Fields could be reallocated under specific conditions such as continued non-use. In some cases land was rented out.

- *Communal rangeland*

In this case an area was designated largely for summer grazing, but was also used for other resources such as water, thatch grass, fuel wood, timber and medicinal plants. All members had access to this area, and usage patterns were controlled by local regulations. Frequency of burning in the communal rangeland was related to the accumulation of herbage, which was generally low because of the high stocking densities. There was no limit to the number of livestock that an individual could keep. In some areas permits were required to keep livestock, but these were not used to control numbers.

Although some communal areas still operate under the “betterment” system, it is no longer functioning in many areas. The main reason for this was the top-down approach, and lack of consultation with the people on key issues such as fence boundaries.

Land reform in South Africa is currently underway to address the past history of unequal land distribution. Many planners have called for privatisation of land to stop overgrazing. However, in many cases resource productivity per unit area is not high enough to guarantee the individual or group the returns needed to sustain private property regimes. In addition, resource poor people that have been allocated private property regimes may not be able to bear the cost that these systems impose. Turner (1995) suggests that the solution to natural resource management problems in southern Africa is to be found in a combination of institutional arrangements

that combine the best attributes of private, common and state property.

7.2.1.2 Social Issues

Past failures of development initiatives to solve the problems of environmental degradation in South Africa have been attributed to the lack of consultation and involvement of the rural population. In the past, the top-down approach to implementing management strategies excluded the local people from decision making. Participation will empower people and give them a sense of ownership in management decisions. New conservation policies are based on the need to adopt more socially responsible methods of conservation management.

7.2.1.3 Ecological Issues (Range and Livestock Management)

When “betterment” was first initiated, a destocking campaign was implemented by the government, but after strong opposition this was discontinued. Traditionally, livestock management was the responsibility of the men, and herding was carried out by young boys. Today, women play a major role in livestock management. As men migrate to industrial and mining sites in search of jobs, women are left in rural areas as heads of households. Although women’s interactions with cattle have increased over the years, decisions on issues such as slaughtering and selling are still vested with the men.

During the 1950s, when “betterment” was implemented, the grazing area was fenced off from the cropping area, and individual grazing camps were also fenced. However, the fencing

system has collapsed, largely through theft and lack of maintenance. It is clear that any cattle and rangeland management strategy will require some mechanism to control cattle movement. Cattle movement can be controlled by physical or social fencing, such as herding.

Management of individual livestock herds on communal rangelands is largely exercised by herders, and the level of herding varies. Over much of the Drakensberg and surrounds, the absence of young boys, who now attend school, imposes a major limitation to livestock management. In Lesotho, however, large numbers of herders guard access to grazing. Increased social development, including improved school attendance, results in a breakdown in the traditional herding system. This causes losses through the theft of stock and conflict between crop and cattle owners, particularly when crops are destroyed by untended cattle. One solution that is currently being examined by communal farmers in the northern Drakensberg region is based on the Lesotho model, whereby herders are paid, either in money or livestock, to look after livestock.

One of the current problems in developing communal grazing systems is the skewed ownership of livestock and the tendency for a large proportion of the livestock to be in the hands of absentee members employed in industry outside the communal area. The livestock, which such individuals accumulate in the communal area primarily for the purpose of storing their wealth, denies the local inhabitants of a large proportion of the resources of the rangeland.

The grazing system in communal rangelands closely follows the cropping cycle. During the cropping season in summer, the cattle herds are moved away from the crop fields to graze on the surrounding natural grasslands. Milk cows and calves are usually kept in the vicinity of the homesteads. In winter, following harvest of the crops, the cattle graze on the maize stalks in addition to rangeland. Fodder shortage, especially during the dry winter season, is one of the main constraints to livestock production.

Rural communities in the Drakensberg region are currently investigating various grazing and fire management options to improve production. One of these initiatives falls under the National Landcare programme, a programme which aims to support community conservation groups in sustainable management practices. Current management initiatives in the Okhombe ward, in the northern Drakensberg, include the resting of a portion of the veld for the entire growing season. Rested veld will then be burned in early spring to increase grass vigour and yield. The introduction of this grazing and fire management system is a complex procedure that has taken over a year to develop, and is still in the planning stage. Critical issues that have been addressed by the community include:

- Training in the principles of grazing and fire management.
- Institutional development and the formation of a livestock committee and monitoring group.
- The development of a participatory impact monitoring programme.

- Community meetings at ward and sub-ward level to obtain agreement on placement of camps.
- Community meetings and decisions on fencing infrastructure. This includes decisions on individual contributions to a fencing fund and submission of proposals to funding agencies for fencing materials.
- Training on how to fence and erection of fences.
- Community decisions on dipping regimes and the incorporation of this into the grazing programme.
- Identification and mapping of water resources.
- Initiation of a programme to improve water resources.
- Mapping of the grazing area.
- Calculation of current stocking densities.
- Meetings with adjacent communities to discuss and reach consensus on boundary issues.
- Meetings with the tribal council to inform them regularly of developments and to gain approval on all community decisions.
- Discussions on herding issues (payment, etc.).
- Creating rules and conditions for participating in the grazing and fire management programmes.

The success of a fire and grazing management strategy will depend on the cooperation of all the role players.

7.2.1.4 Institutional Issues

Communities dependent on common property resources have adopted various institutional

arrangements to manage these resources. The varying degrees of success that have been achieved, is dependent largely on the effectiveness of the tribal elders, managing the communities under their control.

In South Africa the protection and conservation of biodiversity has been carried out largely through the creation of national parks with patrolled perimeters (Diken et al., 1996). Local communities generally did not receive significant benefits from these areas, and often did not have access to the resources. The KwaZulu-Natal Conservation Services is currently investing considerable financial and manpower resources into involving local people and communities in the running of parks and in policy decisions on how they should be managed. Processes are currently taking place whereby local boards are created and community members can be appointed onto these boards, to promote more effective regulation of protected areas.

7.2.1.5 Fire Use in Rural Areas

The main objectives of burning by rural farmers are:

- To burn off unpalatable growth left over from the previous seasons to provide nutritious regrowth for livestock.
- To stimulate out-of-season growth to provide fodder when no other fodder reserves are available.
- To attract game by out-of-season burning.
- To protect homesteads and property against wildfires.



In the past, the management of veld burning in communal areas has received very little attention and support from the government. There are currently no prescribed burning programmes for communal areas. Fires are initiated by individuals and occur throughout the year from April to late summer (January). Concern has frequently been raised by members of the community that this *ad hoc* system poses danger to the safety of homesteads. In spite of the low biomass in these areas, devastating veld fires are common, particularly during August when hot bergwinds prevail. Communities do not have adequate fire

equipment to implement controlled burning. However, there is provision under the new National Veld and Forest Fire Act No. 101 of 1998, to provide training and support to rural communities in the management and control of veld fires. Initiatives in the rural areas of the Drakensberg include the formation of local fire protection associations and the provision for equipment, such as fire beaters. These initiatives need to be expanded to include advice on the principles of burning and institutional development for cooperative burning programmes.

Figure 7.1. High intensity fire in montane grassland (Photo: T.M. Everson).

7.2



7.2.2 Grazing Provision in the Savanna Grasslands of Uganda

Fire has long influenced the development, maintenance and productivity of nearly 80% of the Uganda natural grasslands, which are important for livestock grazing. However, traditional burning appears to reduce the productivity of these natural pastures, especially in the *Acacia*/savanna grassland, since there is no proper fire regime (fire intensity, severity and frequency) used by these pastoralists, as there is limited research that gives reliable data on how to use prescribed fires on these pasture lands (Sabiiti et al., 1986; Sabiiti &

Wein, 1987; Harrington, 1974, in Sabiiti & Wein, 1989). Consequently, most of these pastures have been invaded by coarse and less nutritive grass species (*Cymbopogon*, *Imperata*, *Hyparrhenia* and *Sporobolus*), which appear to be favoured by poor fire management practices.

Studies by Sabiiti and Wein (1989) have proved that maximum grassland productivity can be promoted by high fire intensities during late annual burning because the fire stimulates vigorous grass seed germination and seedling establishment. The old vegetation is then completely burned (by a high intensity fire) and nutrients are returned to

Figure 7.2. Fire in progress in the savanna grasslands of Uganda (Photo: M.C. Calvin).

the soil through the “ash-bed” effect, promoting lush growth. It was recorded that palatable grass species, such as *Brachiaria*, *Panicum*, *Cynodon* and *Setaria*, then become dominant, providing a high percentage crude protein. Early fires, on the other hand, were not as effective in increasing grassland productivity. Fire exclusion clearly showed negative effects on production, as old grasses retarded new growth through shading and competition for nutrients and hence low quality. Such pastures cannot support high cattle productivity. These studies conducted by Sibiiti and Wein (1989) have clearly demonstrated the implication of burning of natural grasslands and its importance for cattle grazing.

There is also a problem of *Acacia*/bush encroachment in the rangelands, which has serious consequences for livestock grazing in Uganda. These trees and bushes have reduced grazable land and suppress palatable grasses such as Congo signal grass (*Bhachiaria brizantha*), Nadi setaria (*Setaria anceps*), green panicum (*Panicum maximum*) and star grass (*Cynodon dactylon*). These rangelands support millions of cattle, goats and sheep (Sibiiti & Wein, 1991).

Studies by Sibiiti and Wein (1991) have indicated that the species *Acacia hockii* has evolved two strategies for survival, namely regeneration from stumps and from soil-seed reserves, and that this growth is very rapid. This growth can easily be controlled by application of high browsing pressure and fire intensity. Burning should be done after felling the trees at the end of the dry season (late burn). Exclusion of browsing and fire are detrimental to the rangeland as this can lead to *Acacia* closed canopy, the disappearance of

palatable grasses and reduced rangeland productivity. Fire alone may also retard *Acacia* tree growth, but will promote seedling emergence and establishment thus increasing tree density (Sibiiti & Wein, 1991).

7.3 USE OF FIRE IN PLANTATION FORESTRY

7.3.1 External Fire Protection

In even-aged industrial plantations, fire protection is required on external plantation boundaries to protect *Acacia*, *Eucalyptus*, *Pinus* and other even-aged timber plantations, from wildfires originating from beyond these plantations' property boundaries. Lands outside plantations may consist of some form of natural vegetation (such as woodland, indigenous forest, fynbos or grassland), which may fall under the control of nature conservation bodies (such as nature reserves) or agricultural land used for grazing or growing of short-rotation crops (such as sugar cane). Industrial plantations can also border public roads or railway lines, rural or commercial farming communities, the urban-interface areas of cities, or industrial sites. These different types of land-use along plantation borders all present varying degrees of wildfire hazard to plantation timber resources.

External fire protection in the form of fire breaks can be provided along plantation boundaries in various ways, such as:

- Yearly burning of grassland
- Yearly slashing and burning of grassland
- Burning of fynbos vegetation
- Ploughing of fire breaks



- Scraping of fire breaks
- Hand-cleaning (or fuel removal within) fire breaks
- Maintaining (or scraping) of roads on external boundaries.

7.3.2 Maintaining (or Scraping) of Roads on External Boundaries

External boundaries are not always the best protective lines to prevent wildfires from spreading into plantations. They are mostly man-made, and often have not been demarcated along optimal topographical features in the landscape. This problem is commonly experienced where protection lines are directly facing the direction of the most serious fire hazard threat during the fire season (i.e. mostly from the north-west in the summer rainfall region). For that reason, regional buffer-zones are sometimes used to replace external fire breaks (De Ronde & Masson, 1998).

Where possible, external fire breaks should be annually burned before the fire season where plantations are bordering natural grassland (e.g. in the summer rainfall regions). They are normally burned after grassland curing has commenced. Before curing starts, tracer lines are prepared by

means of chemical surface sprays so that the grass within these lines desiccates and can be burned before the adjacent cures. This is done to make certain that these lines are in place before the prescribed burning season. The grassland between these tracer lines is then burned on suitable prescribed burning days, as soon as possible after grassland curing is completed.

Sometimes external fire breaks are strengthened by boundary roads or prescribed-burned plantation stands, and should be as wide as possible, particularly when facing the dangerous north-westerly direction. When facing less dangerous directions/topography, minimum requirements (such as boundary roads, ploughed lines or even burned tracer lines) can provide cheaper (but still adequate) protection. More detail regarding prescribed burning application techniques will be provided in Chapter 13.

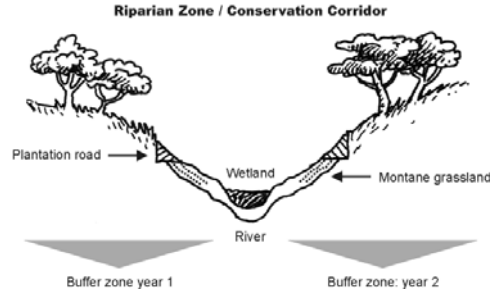
7.3.3 Internal Fire Protection

It is equally important to reduce fire hazard within plantations and provide internal fire protection. Fires can originate within plantation blocks, or external wildfires can spot or burn across external firebreaks. If this happens, internal fire breaks

Figure 7.3(a). Illustration of a mechanically-cleared fire break in the Western Cape, South Africa (Photo: C. de Ronde). **Figure 7.3(b).** A grassland fire break in the north-eastern Cape, South Africa. Note that this protective line is not well placed (on the steep slope), and that it may cause erosion. It should ideally have been placed along the crest of the mountain (Photo: C. de Ronde).

will have to ensure that the spread of these fires within “plantation areas at risk” is restricted to the smallest area possible, and the smaller (and better protected) these plantation units are, the better will be the chances to bring these internal fires under control, and to minimise damage. Clean roads within plantation blocks, regularly-burned wetlands, indigenous forests, steep (rocky) terrain with low fuel profiles, rivers with riverine forests and slash-burned compartments, are all examples of suitable internal protective barriers that can be incorporated into internal fire break systems. The more continuous these lines are, the better the chances will be to restrict wildfires within plantation boundaries (De Ronde & Masson, 1998).

It the case of wetland grasslands that have to be burned on two- to four-year rotations, it is better to burn these areas under controlled conditions yearly by riverside or by watershed (one side of the stream/river course at a time), than to burn both sides of a river/wetland simultaneously. The latter will not provide continuous protective lines, but a mosaic of burned and unburned areas with little fire protection value. Some of these protection areas (particularly prominent riparian zones) can even be strengthened on both sides by prescribed-burned plantation strips, to form major bufferzone systems through large plantation blocks. These can sometimes even be incorporated into the regional fire break (bufferzone) systems. Such “watershed lines” – also acting as fire breaks – can also be utilised as “wildlife corridors” and even facilitate optimised water runoff, thus forming multi-purpose fire management systems (De Ronde & Masson, 1998; Figure 7.4).



Where montane grassland on higher ground is incorporated in external or internal fire break systems, an optimum burning regime of a two- to three-year rotation is normally required to maintain biodiversity within these natural systems. Where yearly fire protection is required within these grasslands, wide burning strips should be burned along these lines on a rotation basis, to satisfy both fire protection and ecological requirements. Alternative fire break routes should be investigated where these requirements cannot be met (De Ronde, 1998).

7.3.4 Using Slash Burning as a Fuel Management Measure

Because of the clearfelling regime applied in even-aged industrial plantations, slash is deposited in large quantities where mature trees are felled and exploited, prior to re-establishment. In many cases this litter-and-slash loading occurs in low quantities, which will not present tree re-establishment problems. However, in some areas, particularly in *Pinus patula* stands at high altitude, and in *Eucalyptus* stands after three or more short-term coppice rotations without slash burning, the slash loading reduces access and replanting is

Figure 7.4. Cross-section of an ideal riparian zone and conservation corridor maintained by prescribed burning, simultaneously providing adequate protection for fire protection purposes (De Ronde & Masson, 1998).

7.5



severely restricted. It is then that some degree of fuel reduction will be required to make the economical re-establishment of trees possible. Sometimes slash burning will have to be applied regardless of whether the fuel loading is restricting access for replanting purposes or not, because the stand is either bordering a major fire protection bufferzone, or falls within a major bufferzone/fire break area (De Ronde & Masson, 1998).

It is important to evaluate slash features such as loading, spread and vertical distribution in clearfelled stands to determine whether slash burning should be considered as a fuel reduction measure or not. Slash burning should be avoided on sandy soils because these sites can be very poor in nutrients and availability. However, if slash burning cannot be avoided on these sites, the

impact of these burns on nutrients should preferably be determined by means of the collection and analysis of surface soil samples (sampling to be applied before and after the burn). This determining of nutritional requirements, prior to tree establishment, is particularly important in the case of expected nitrogen deficiencies (De Ronde & Zwolinski, 2000). Slash burning on steep slopes should also be avoided to prevent erosion.

Rhizina undulata may present problems after slash burning on some sites, and all slash-burned stands should preferably be left unplanted for up to three or four weeks following burning application, so they can then be inspected for any sign of *Rhizina* fruiting bodies. If identified, replanting should be postponed until the *Rhizina* fruiting bodies dry out and die. The same applies to stands

Figure 7.5. Burning of slash rows inside a 12-year-old *Pinus patula* stand on the Mpumalanga Highveld, South Africa (Photo: C. de Ronde).

that have been exposed to wildfire, with subsequent complete fuel consumption (De Ronde et al., 1986).

With regard to slash burning techniques to be used, broadcast burning of slash (after spreading the slash when timber removal is completed) is recommended in most cases because (a) it has proved to be the safest and cheapest method, and (b) stacking of slash in heaps and then burning the heaps has not only proved to be more expensive, but is also exposing the soil to high fire temperatures for longer periods of time, which can be detrimental to chemical and physical soil properties (De Ronde, 1990; De Ronde & Zwolinski, 2000). Burning of inherited slash rows is, however, a viable option when converting *Eucalyptus* coppice stands to *Pinus* spp. (pers. comm., B. Potgieter, Sappi Forests, Lothair, Mpumalanga, South Africa).

7.3.5 Fire Application in Heritage Areas and Nature Reserves

Where natural heritage areas are situated within plantation boundaries, special care will be required when prescribed fire is to be applied. Where bushman paintings, ancient villages or other prehistoric sites are found, care should be taken to apply fire in such a manner that no damage (such as scorch) is caused. Preventative measures in the form of physical fuel removal around the site, or fire application only when the wind blows from a specific direction (away from the site), may be required, or will be stipulated as written rules in the fire protection plan.

In nature reserves within plantations, the general norm will be to burn according to ecologi-

cal requirements, which will then apply to that specific ecosystem base. Most montane grasslands, situated outside fire breaks, will require a burning rotation between two and four years, but the burning regime may differ for specific wetlands, where it can be between three and five years. In fynbos nature reserves the required burning rotation will probably be between 12 and 20 years. Special care should be exercised when prescribed burning is applied around patches of indigenous forests, to protect the forest edge. A 50 m burning-free area is the minimum protective area that is normally required to allow forest regeneration to develop without disturbance. Where fire breaks are situated close to indigenous forest patches, burning should be applied in such a way that the fire line is ignited so that it moves away from the forest edge, to avoid damage as a result of scorch from the heat of the fire.

The creation of natural corridors through areas covered by plantations – making use of major wetland/river lines and mountain crests – should be considered where bufferzones are placed and maintained. This will provide free access between grassland sites for mammals such as grazers, within and outside plantation boundaries. Two- to four-year rotation burning should be applied within these corridors where possible, depending on ecological requirements (see Figure 7.4).

Other important issues to consider are the protection of breeding areas for rare bird species within plantation boundaries, and to avoid any fire application too close to these nesting sites. Some species – such as rare Eagle and Vulture species – may prefer steep mountainous terrain for nesting platforms, while others – such as the rare

Wattle Crane (*Bugeranus carunculatus*) and Marsh Owl (*Asio capensis*) – may prefer wetlands or marshes to breed. In each case it is important to identify and map these nesting sites, and to avoid any burning operations close to these sites during the breeding period.

Where nature walks and trails exist within plantation property boundaries, care should be taken to apply fire protection in such a way that the immediate area surrounding these routes is burned in a prescribed sequence so that no large areas are blackened simultaneously, but rather burned in strips or blocks in rotation, with footpaths forming the fire break tracer lines, where possible.

7.3.6 Wildfire Bufferzoning and other Fire Protection Techniques

In many cases, bufferzoning along specific lines – normally facing the direction of hazardous wildfire threat at an angle – are constructed, with a width of up to 500 m or even wider, to replace inadequate fire breaks. The placement of bufferzones should preferably be done by a qualified fire management specialist, who can identify optimum routes in the landscape and calculate minimum fire protection requirements. It is also important to start fire protection evaluation by considering regional requirements before changing any within-plantation fire breaks, and to make sure that these zones also comply with ecological and riparian zone specifications (De Ronde & Masson, 1998).

Many times bufferzones follow natural fire barriers such as steep terrain, existing indigenous forests or major rivers with riverine forests, but where these are not available, man-made lines such as public roads, railway lines or powerlines

can also be used as a bufferzone base. In most cases a combination of natural and man-made fire protection areas, with some form of fuel restriction, will be used for bufferzones. Yearly-burned grassland, or fynbos rotation burns, can form the backbone of these fire break systems (De Ronde, 1990).

Where plantation stands have been identified as forming rather weak links in fire break or bufferzone lines, incorporation of these stands as prescribed burned areas should be considered. Sometimes species and/or stand age may not yet be suitable for prescribed burning application, in which case temporary alternative routes should be investigated until such time that these stands have reached the correct age, or species have been changed. For important bufferzones it may be necessary to change to more fire resistant species to facilitate regular prescribed burning application on a rotation basis (such as to *Pinus elliottii*). Alternatively, alternative temporary fuel reduction measures – such as the yearly weed control in *Eucalyptus* stands within bufferzones and external fire breaks – may be considered to plug weak gaps if no alternative routes are available, and until better fire protection measures can be provided (De Ronde, various regional plans). The planting of Wattle (*Acacia mearnsii*) for fire protection purposes has also been used successfully in some summer rainfall regions of southern Africa (De Ronde, 1997). Mature stands of the species can provide compact, low profile, litter layers when the crown canopy is closed, and because these stands are known to be able to stop serious wildfires when nothing else can (De Ronde, pers. obs.). One requirement will be that

these stands must have been well managed and not have developed into “Wattle jungles”, as these areas can create a fire hazard instead of being suitable for fire protection purposes (De Ronde, pers. obs.). Regeneration outside Wattle stands should also not be allowed, to avoid the development of external weed problems.

Fire protection techniques (or fire break management procedures) other than regular vegetation burning – such as slashing, hoeing or some forms of soil preparation – may sometimes present viable options for fuel reduction if regular prescribed burning is not possible. However, it must be kept in mind that these may still present some fuel residue – e.g. slashing of fuel still presents the same fuel loading, although the depth of the fuel bed (surface-to-volume ratio) has been reduced. Methods such as ploughing or scraping of roads can also be used effectively to create fuel-free fire protection lines if applied correctly.

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8

REMOTE SENSING OF VEGETATION FIRES AND ITS CONTRIBUTION TO A FIRE MANAGEMENT INFORMATION SYSTEM

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8.1 BACKGROUND

In the last decade, research has proven that remote sensing can provide very useful support to fire managers. This chapter provides an overview of the types of information remote sensing can provide to the fire community. First, it considers fire management information needs in the context of a fire management information system. An introduction to remote sensing then precedes a description of fire information obtainable from remote sensing data (such as vegetation status, active fire detection and burned areas assessment). Finally, operational examples in five African countries illustrate the practical use of remotely sensed fire information.

8.2 FIRE MANAGEMENT AND INFORMATION NEEDS

As indicated in previous chapters, fire management usually comprises activities designed to control the frequency, area, intensity or impact of fire. These activities are undertaken in different institutional, economic, social, environmental and geographical contexts, as well as at different scales, from local to national. The range of fire management activities also varies considerably according to the management issues at stake, as well as the available means and capacity to act. Whatever the level, effective fire management requires reliable information upon which to base appropriate decisions and actions. Information will

8.1



be required at many different stages of this fire management system. To illustrate this, we consider a typical and generic description of a fire “management loop”, as provided in Figure 8.1.

- *Fire management objectives* result from fire related “knowledge”. For example, they may relate to sound ecological reasons for prescribed burning in a particular land management context, or to frequent, uncontrolled fires threatening valuable natural or human resources. Whatever the issues, appropriate objectives require scientific knowledge (such as fire impact on ecosystems components, such as soil and vegetation), as well as up-to-date monitoring information (such as vegetation status, fire locations, land use, socio-economic context, etc.).
- *Policies*, generally at a national and governmental level, provide the official or legal long-term framework (e.g. five to ten years) to undertake actions. A proper documentation of different fire issues, and their evolution, will allow their integration into appropriate policies, whether specific to fire management, or complementary to other policies in areas

such as forestry, rangeland, biodiversity, land tenure, etc.

- *Strategies* are found at all levels of fire management. They provide a shorter-term framework (e.g. one to five years) to prioritise fire management activities. They involve the development of a clear set of objectives and a clear set of activities to achieve these objectives. They may also include research and training inputs required, in order to build capacity and to answer specific questions needed to improve fire management. The chosen strategy will result from a trade-off between priority fire management objectives and the available capacity to act (e.g. institutional framework, budget, staff, etc.), and will lead towards a better allocation of resources for fire management operations to achieve specific objectives. One example in achieving an objective of conserving biotic diversity may be the implementation of a patch-mosaic burning system (Brockett et al., 2001) instead of a prescribed block burning system, based on an assumption that the former should better promote biodiversity in the long-term than the latter (Parr & Brockett, 1999). This strategy requires the implementation of early season fires to reduce the size of later season fires. The knowledge of population movements, new settlements or a coming El Niño season, should help focus the resources usage, as these factors might influence the proportion as well as the locations of area burned. Another strategy may be to prioritise the grading of fire lines earlier than usual based on information on high biomass accumulation.

Figure 8.1. Typical fire “management loop”.

However, whatever the strategies, they need to be based on reliable information.

- *Operational fire management* concerns the implementation of the strategy. Daily activities will also be most effective if based on reliable and up-to-date information. For example, an accurate knowledge of fire frequency, fuel load, fuel status and meteorological conditions across the management area will help to inform the choice and timing of areas for ignition within a prescribed burning programme; early detection of active fires in relation to their potential impact will help prioritise the activities of fire fighting teams.
- *Research* activities may require a range of studies – from long-term to short-term/one-off – in order to answer specific questions of concern to improving fire management.
- *Monitoring and evaluation* activities are essential to close the “management loop”. They allow the assessment of the effectiveness of different strategies, to document the current situation, and to learn from the past in order to adapt and improve knowledge and management activities for the next loop.
- *Repeating the loop* is also an essential part of management, in order to evolve with the natural, economic, and societal changes. Updated information will always be required to act appropriately.

A Fire Management Information System (FMIS) is an important tool to support integrated fire management. It allows for incorporating information and knowledge from various sources and integrating them into thematic information in

direct support of specific decisions. FMIS can include information such as:

- Fire events over the years (e.g. where, when and how often have areas burned).
- Information that may be related to the fire events (e.g. what vegetation was burned, ecological knowledge obtained in the field, desired fire regimes, areas where fires are acceptable/unacceptable (under management or not), why fires are set, attitudes of different people towards fire and fire prevention, population density, meteorological data, vegetation status, economical assets).
- Ancillary information (e.g. roads and river networks, administrative boundaries, protected areas, concessions, villages, fire towers, fire fighting units).
- Modelling tools, e.g. fire prescription models, fire danger models and fire spread models.

Fire is seen as an efficient tool in the management of (often) large areas of land (Bond & Van Wilgen, 1996). However, whilst field observations will always be a vital part of fire management, the very size of the areas in question often means that field observation alone cannot provide sufficient information with sufficient accuracy and regularity to provide a reliable basis for fire management. Such problems are compounded in countries and regions where resources and local staff are particularly constrained. Many studies have demonstrated the potential usefulness of remote sensing techniques for monitoring the Earth's surface and providing fire related information in particular (e.g. Kaufman et al., 1990; Pereira et al., 2000).

Due to a high correlation between variations observed from remote sensors and variations on the Earth's surface (Congalton & Green, 1998), remotely sensed data provide an excellent basis for monitoring parameters of interest to fire managers, such as biomass, vegetation status, the occurrence of active fires and the delineation of areas that burn. It works because the Earth's surface reflects light and emits energy differently according to its land cover type, status, quantity and several other factors. The technology can give the geographical location of any point of an image, therefore allowing its combination with other geographic information such as roads, fire units, protected forest, plantations, villages and other fire-related information, as well as the cross-comparison of images taken at different times within and across seasons.

The benefits that remotely sensed data provide to fire management include:

- It is often less expensive and faster than obtaining the same information on the ground over large areas.
- It permits the capturing of data across a wider range of the electromagnetic spectrum than can be seen by humans. This can allow the extraction of a wider range of fire-related information.
- Observations are spatially comprehensive. They cover large areas of territory (e.g. the whole of Ethiopia at once), including areas that are remote and difficult to access by land.
- In the case of satellite observations, observations are regular (e.g. daily), allowing for frequent updates of the situation.
- Because the satellite orbits Earth continuously, observations are reliable, systematic and objective (i.e. the same place can be imaged repeatedly with the same sensor).

8.3 REMOTE SENSING DATA: INTRODUCTION

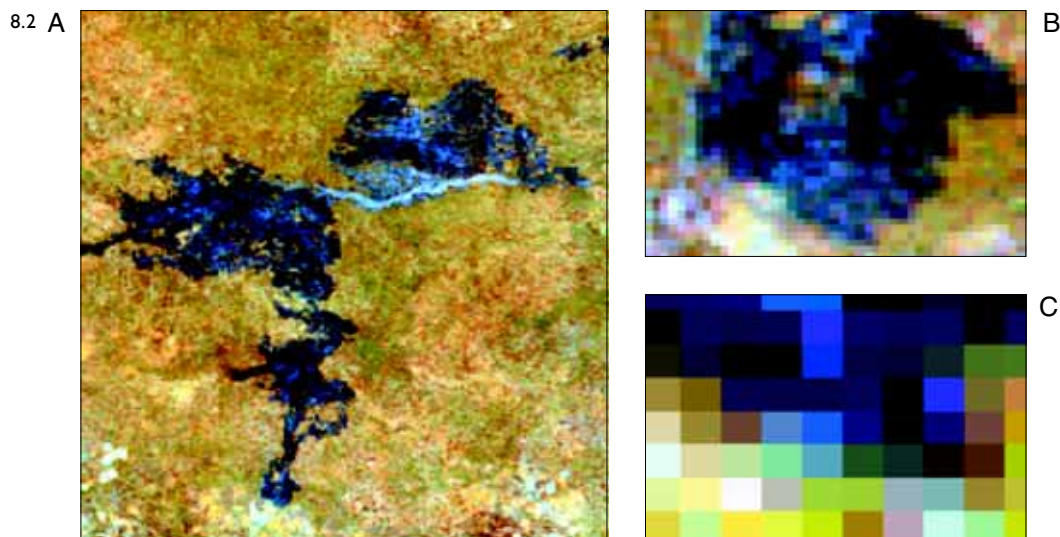
8.3.1 A Short Introduction to Remote Sensing

One of the simplest, broad definitions of remote sensing is that given by Lillesand and Kiefer (2000):

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation.

You are therefore using remote sensing as you read these words! Your eyes are sensing variations in light from the page and your brain is interpreting this "data" so that you can understand the information that the words convey (Lillesand & Kiefer, 2000). Other definitions add that the information is usually derived about the Earth's land, water and atmosphere from *images* acquired at a distance, based on the measurement of electromagnetic energy from these features (Campbell, 1987).

In the context of Earth observation remote sensing, an image is generally a picture received from a satellite or an airborne sensor. Digital images from satellite remote sensing are useful for fire monitoring because they:



- Allow low cost, rapid and regular coverage of the often extensive and inaccessible areas affected by fire.
- Permit capture of types of data that humans cannot sense, such as the near-infrared and thermal part of the electromagnetic spectrum, which may provide additional useful information.

Here we briefly introduce the general characteristics of digital images, mostly from space-borne sensors, as a potential source of information for fire management. As different sensors provide images with different characteristics, we focus on criteria commonly used to evaluate and compare imagery from different sources. Annexure I summarises satellite sensors currently providing data for Africa.

8.3.1.1 Spatial Resolution

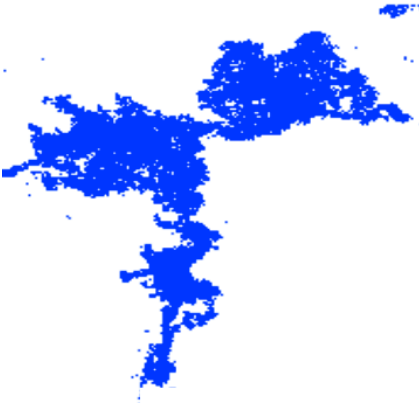
An image may look, at first sight, like a photograph. However, enlarging the image reveals that it is actually made up of many small square blocks, called pixels (short for picture elements).

All sensors have a limit on how small an object on the earth's surface can be and can still be seen by a sensor. This limit is known as the spatial resolution and is related to the image pixel size. The 30 m spatial resolution of the Landsat-TM image, used in Figure 8.2, renders a detailed view of a burned area, with the complex perimeter and unburned islands of vegetation clearly visible.

The low spatial resolution NOAA-AVHRR sensor uses a pixel size of 1.1 km, which means that most objects smaller than 1 km cannot be detected reliably (with active fires being an important exception). Figure 8.3 shows how the same burned area was mapped from TM

Figure 8.2. In the overview image (A), a burned area is clearly evident in shades of medium to dark blue. Unburned vegetation appears green. With increasing magnification (B), the image appears more “grainy”, until in (C), individual pixels – that make up the image – can be seen. The image is made from TM data with a spatial resolution of 30 m. The intensity, or brightness, with which each pixel is displayed, is proportional to the average brightness, or radiance, measured electronically over the ground area corresponding to each pixel.

8.3 A



B



and AVHRR data. The images reveal the degree of simplification inherent at coarse spatial resolution.

8.3.2 Swath Width

Sensors on polar orbiting platforms cover a “swath” or “strip” of the Earth’s surface, with the width of the swath, and hence the width of the image, depending on the particular sensor. In general, broad-swath imagery (e.g. 2700 km wide) is well adapted to the frequent observation of large areas, but at the expense of spatial detail, while narrow-swath imagery (e.g. 185 km wide) provides the spatial detail but is available less frequently.

8.3.3 Temporal Resolution

The frequency with which a satellite is able to take an image of a particular area of ground is also important. The time interval between images is called the return period. The shortest reliable return period is known as the temporal resolution of the sensor. This usually varies between 15 minutes to over 30 days, depending on the satellite.

The temporal resolution is largely determined by the orbit characteristics of the satellite, but the spatial resolution of the sensor will also affect this. For example, the NOAA AVHRR sensor scans a continuous swath 2700 km wide and can image the entire earth surface twice per day, but at a spatial resolution of only 1.1 km. A SPOT sensor covers a swath around 60 km wide with a spatial resolution down to 3 m, but the narrow swath means that it takes 26 days to image all of the Earth and therefore one place is only revisited every 26 days (see Annexure 1).

8.3.4 Spectral Resolution

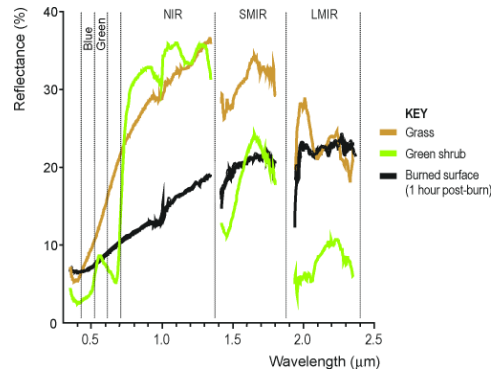
The human eye can see many different colours that, taken together, make up visible light. Visible light is only one of many forms of electromagnetic energy. Radio waves, X-rays and ultraviolet rays are other familiar forms. All electromagnetic energy travels in waves at the speed of light. The distance from one wave peak to the next is called the wavelength. The electromagnetic spectrum is divided up according to wavelength (usually measured in micrometers – μm), although there

Figure 8.3. The same burned area, (A) mapped from TM data with a spatial resolution of 30 m and (B) mapped from AVHRR data with a spatial resolution of approximately 1.1 km (at best). Although the burned area is approximately the same shape in both pictures, the AVHRR representation is highly simplified compared to using TM, illustrating the loss of detail at lower spatial resolutions.

are no clear-cut dividing lines between the different regions. Satellite sensors are sensitive to a much wider range of wavelengths than that of visible light. Sensors effectively “see” at wavelengths that are invisible to the eye, and this often allows more information to be obtained about objects than would be possible by simply looking at them.

Objects reflect and emit different amounts of radiation at different wavelengths. In the visible to mid-infrared, this response is measured using reflectance. In practice, satellite sensors usually provide each image in a number of different bands or channels. Each band is sensitive to electromagnetic radiation over a restricted range of wavelengths. By strict definition, the narrowness of this range gives the spectral resolution of the band. However, in the context of satellite remote sensing, spectral resolution can be more usefully interpreted as the particular band used. The sensor makes measurements of the total response across the particular band used. No more precise reading can be made by this sensor within the band.

Comparing reflectance spectra of different surfaces can help to determine which bands are most appropriate for looking at each cover type. Figure 8.2 shows an example of reflectance spectra for a burned surface, green shrub and senescent grass. The approximate wavelength intervals (blue, green, red, near infrared [NIR], short mid-infrared [SMIR] and long mid-infrared [LMIR]) are also shown. It is possible to distinguish both vegetation types from the burned surface in the near infrared, because the reflectance of the burned surface is low and the reflectance



of the vegetation is high. Hence they will appear dark and light respectively on a near infrared image band. At visible wavelengths, the two vegetation spectra (particularly shrub) are similar to the burned surface, suggesting that visible bands do not provide good contrast between burned and unburned vegetation. In the SMIR, only grass contrasts strongly with the burned surface, whilst in the LMIR, only shrub has good contrast.

Clearly, discrimination between surfaces depends on the band used. In fact, sensors that take measurements in few broad bands offer less potential information than sensors that measure EM energy in many bands positioned over a wider range of wavelengths. For example, panchromatic air photos (i.e. sensitive to all colours) are sensitive to light reflected from the surface (approximately analogous to having one band in the visible). Using these photos, some burned areas can only be interpreted reliably up to three days after the fire. In contrast, data from the Landsat-TM sensor, provided in seven bands over a much wider spectral range, can identify the same burned area months after burning. Similarly, other combinations of spectral bands can be used to

Figure 8.4. Spectral response (variation of reflectance with wavelength) of a burned surface, compared to senescent grass and green shrub. The approximate wavelength intervals are also marked with dashed lines.

derive other fire-related information such as active fires and fire risk.

8.3.5 Cost

Data costs vary from free, unlimited access to all available images (as is the case with AVHRR data, so long as the necessary receiving equipment is in place, and for MODIS), to costs of well over one thousand US dollars for each image acquired. In general, prices increase with spatial resolution. Low to moderate spatial resolution, free data (e.g., NOAA-AVHRR and MODIS) can be very useful for fire management.

8.3.6 Operational vs. Research Satellite Programmes

Operational satellite programmes are organised to guarantee the routine availability of particular kinds of remotely sensed data from the same type of instrument over extended or indefinite time periods. As such, they offer a very important resource for comparing patterns and trends in surface cover and processes between years. For example, the NOAA-AVHRR has provided data operationally since 1979, which has been used in studies of global change, and is a valuable resource for studying fire patterns over the years.

Research satellite programmes do not place the same guarantees on prolonged availability of data, and are primarily aimed at demonstrating or using improved technology to provide better information. As such, they are also important potential sources of improved fire management information, but there are less guarantees as to how long into the future the data will remain available.

8.3.7 Data Access

Remotely sensed data has in general become easier, cheaper and quicker to access through time. Initially, all data had to be ordered from large, centralised receiving stations, usually far from the institutions requiring the data. Raw data was usually delivered on tape, or as hardcopy, which could mean having to wait several weeks to obtain it. The advent and rapid development of personal computers, combined with improvements in receiving hardware, resulted in PC-based receivers that allow local institutions to access low spatial resolution imagery themselves, in near-real time. For example, LARST (Local Application of Remote Sensing Techniques) receiving units provided direct access to AVHRR or Meteosat data in many organisations in over 40 different countries (Williams, 1999; Downey, 1994). Further advances in technology resulted in portable, high specification receiving stations capable of allowing local institutions to collect their own images directly from high spatial resolution sensors such as Landsat-TM, ERS-SAR and SPOT-HRVIR (Downey, 2000).

With the advent of the internet, organisations who launch satellites are increasingly providing images and other products online, for rapid access by end-users. For example, fire and other data from the MODIS sensor is obtainable over the internet free of charge and data from the operational SPOT VEGETATION sensor is also available online.

At the time of writing, most high spatial resolution satellite data is still received through a network of few ground stations, and their distribution organised centrally.

Clearly, choosing a sensor and route to provide particular fire management information will require careful consideration of the above aspects, to identify a data source suitable for providing the desired information of the area of interest with sufficient detail, accuracy, regularity and economy, to support specific fire management objectives. Some of these issues are explored further in the section on burned area products (8.4.3).

8.3.8 Other Considerations

It is worth mentioning some additional characteristics of remotely sensed data that the fire manager will need to bear in mind. Thick cloud cover will obscure the surface in most bands used in operational remote sensing for fire (only radar observation can go through clouds). The same is valid for thick smoke (except at the mid-infrared). Centralised receiving stations usually provide browse products of the images on offer that can be visually inspected for cloud and smoke, so that cloud-free images can be identified and ordered.

The accuracy of maps made from remotely sensed data is variable and depends on many factors, and quality control is therefore important at all stages of map production. It is extremely important to choose a data source that will register the different features to be mapped with distinctly different levels of electromagnetic response. Spatial, temporal and spectral resolutions are all important in this regard. Secondly, having identified an appropriate data source, a robust method must be chosen and applied to extract the desired information and deliver the final map. Uncertainty in the accuracy of maps derived from remotely sensed data generally increases with

decreased spatial resolution, spectral resolution and longer return periods. As we have seen, the accuracy of maps made from low spatial resolution data is inherently limited by the low spatial precision of the raw data.

Realisation of the full potential of any maps made from remotely sensed data therefore requires the accuracy of the map to be assessed. This can be done quite simply by collecting a sample of reference data (assumed to be true) at representative locations, which are then compared with the same locations on the map. The overall accuracy can then be estimated, as well as other measures of accuracy, that are of direct interest to the producer and users of the map. This can then help to ensure the adequacy of the maps (and hence the data source and methods used) for providing the required management information. Congalton and Green (1999) provide a comprehensive introduction to both the principles and practices of assessing the accuracy of remotely sensed data.

8.4 REMOTE SENSING PRODUCTS FOR FIRE MANAGEMENT

8.4.1 Introduction

Remote sensing data can assist fire management at three stages relative to fire occurrence:

- *Before the fire*: fuel load, vegetation status (e.g. degree of curing, moisture content) and rainfall.
- *During the fire*: near real-time location of active fires.
- *After the fire*: assessment of burned areas.

8.5

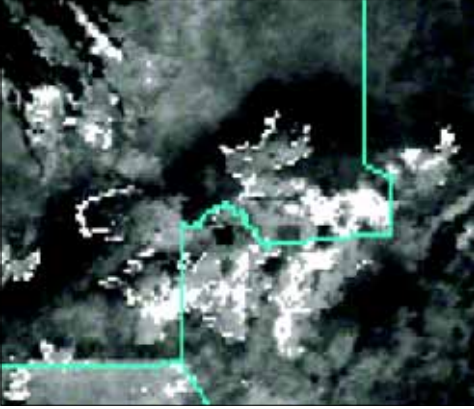


Figure 8.5 gives a basic idea of how fire activity at the surface of the Earth is seen from space. In this case, using a thermal image that is presented so that hot areas appear relatively bright and cooler areas are relatively dark. As one might expect, active fire fronts and burned areas stand out as bright features that contrast well with cooler areas such as smoke and unburned vegetation.

From this simple example, we might conclude that the extraction of active fires, burned areas and other fire-related information from remotely sensed data should be straightforward. However, in reality, it is often far from trivial. In our example, are the observed bright areas in Figure 8.5 definitely active fires or are they burned areas, and how do we distinguish between the two? Are cold areas smoke or vegetation or even water? Are the different features best distinguished using a thermal image alone?

The sensor on board a satellite platform (or a camera on board an aircraft) only observes electromagnetic (EM) radiation coming from the surface of the Earth. Proper extraction of adequate

information requires methods that are based on the knowledge of how fire-related features impose variations in radiation quantities that are measurable by remote sensors. The observed surface radiation can come from reflected sunlight or from emission by the surface itself.* For example, a fire will be hot and reflective, whereas water will be relatively cold and unreflective, both leading to different quantities of radiation being measured by the sensor. Using these differences and variations, digital processing methods, known as *algorithms*, can be designed to extract (from the signal) information in terms of active fires, burned areas, fuel load, vegetation moisture and rainfall. If appropriate methods for digital image processing are unavailable, images can be interpreted visually using similar techniques to air photo interpretation, with the interpreted areas either digitised from a computer-displayed image, or drawn on hardcopy.

It is important to realise that the accuracy of fire information obtained from remote sensing will vary considerably, depending both on the characteristics of the sensor used to obtain the raw data, and on the precision or appropriateness of the algorithm or visual interpretation used to transform the raw data into fire information. It is therefore important that measures are taken to assess the quality or accuracy of any information obtained from remote sensing. This is a vital step to ensure that the best information extraction techniques are chosen, to allow accuracy to be improved where necessary, or to at least ensure that any inherent limitations are accounted for realistically when making decisions based on the remotely sensed information. In short, the right

Figure 8.5. Thermal image from the AVHRR sensor, over northern Botswana. White is hot, and black is cold.

* In the case of “active” remote sensing (such as some radar systems), sensors actually measure the quantity of radiation, initially sent by the sensor itself, which bounces back from the earth surface. These are so far not used very much in the field of fire monitoring, and are not detailed here.

decisions can only be assured if the accuracy of the remote sensing technology is quantified and where necessary accounted for.

The following sections of this chapter describe various remote sensing products useful to fire management, covering their use and the method for their extraction.

8.4.2 Active Fires

Active fires can be detected from satellite data because fire fronts are very hot and emit large amounts of energy that can be observed by thermal sensors onboard satellites or aeroplanes. The identification of fires in an image is now relatively well mastered, and remaining limitations are mostly due to the sensor in itself. The basic active fire product is a list of locations (latitude and longitude) corresponding to pixels detected as having an intense source of heat in the area of land they cover.

8.4.2.1 Active Fire Product in Fire Management

Once integrated into a fire information system, the list of fire locations can be used in two main ways:

- *In near-real time*, to prioritise resources for fire fighting. Within minutes of the satellite overpass, the fire manager can locate active fires on the territory of responsibility. Introduced into the fire information system, the importance of a fire can be considered. For example, a fire in an agricultural area, at the time of land preparation, may mean a controlled *good fire*, presenting no risk. On the

other hand, an unexpected fire near a coffee or a young palm tree plantation, for example, may be more important to tackle. Fire locations can also be used, on a daily basis, to monitor, for example, that planned prescribed burning is actually taking place.

- *As post-fire information*, the active fire product can be used in several ways. Firstly, it can support a policing role. When officers go out in the field to see farmers and villagers, fire maps can provide strong evidence that there is official monitoring and therefore can be useful to promote alternative or preferred fire practices. Secondly, active fire products can be used to document fire activity in a park, over a municipality or over a whole country. They have been used in this way since the mid-1980s. Due to the nature of active fire observation (see further discussion) as well as scientific progress, the direct mapping of burned areas is increasingly seen as a way of providing more complete fire figures. Nevertheless, active fire locations still remain valuable and complementary products in, for example:
 - Documenting the extent of individual fire fronts and the size of fires that contribute to the burned area mosaic.
 - Documenting trends over the years.
 - Documenting the type of fires according to the vegetation in which they occur.
 - Identifying areas of particular human pressure on natural forest.
 - Monitoring and evaluating fire strategies (prescribed burning, awareness campaigns, etc.).

8.4.2.2 Operational active fire products

There are a number of satellite and airborne remote sensing systems which can contribute to fire monitoring from space, including NOAA-AVHRR, Landsat-TM and MSS, SPOT, GOES, DMSP, ERS-ATSR, JERS and MODIS. The temporal, spectral and spatial characteristics of these instruments provide a wide range of sensing capabilities (Justice et al., 1993) and some of them have been shown to be well adapted to fire detection applications. However, the usefulness of operational near real-time fire detection from space is obviously very much dependent on observation frequency.

High spatial resolution satellites, such as Landsat and SPOT, can contribute to fire monitoring, but their cost, their centralised receiving stations and especially their low temporal resolution, limit their use on an operational basis. Meteorological satellites are more appropriate because of their high repetition coverage. The Meteosat geostationary satellite series* covers Africa and Europe, and provides images every 30 minutes (Meteosat Second Generation satellite, launched in mid-2002, provides an image every 15 minutes, with improved channels for fire information). The polar orbiting NOAA series acquires images over the same area every 12 hours by the same satellite, and covers the entire world. There are early afternoon and early morning passes available, as there are two operational satellites. High temporal frequency is especially useful if the data can be acquired, analysed and disseminated in near real-time. Satellites such as NOAA and Meteosat broadcast their data continuously and only require small receiving stations. A number



of these stations are distributed all over the world. Local acquisition of data free of charge, analysis *in situ*, and fast dissemination of fire information is possible with these two satellite series (e.g. Jacques de Dixmude et al., 1999).

Several authors have developed algorithms for active fire detection with AVHRR data. The reader will find a good review and further details on these algorithms in Martín et al. (1999). They are all based on using AVHRR mid-infrared channel, most suited to be sensitive to fire front temperature level.

There are many factors that can affect the detection, such as cloud and smoke, hot soil and sun glint on water. Flasse and Ceccato (1996) developed a contextual method designed to be robust and automatic, for operational use. It is used operationally in several tropical countries (e.g. Flasse et al., 1998). It has also been the basis for global fire detection activities such as the IGBP-Global Fire Product and the World Fire Web of the Joint Research Centre (see <http://www.gvm.jrc.it/TEM/wfw/wfw.htm>).

Up to now, it is essentially NOAA-AVHRR that has provided long-term, continuous operational satellite-based systems, allowing low-cost direct

Figure 8.6. Fire pixel interpretation.

* Its sister, covering the Americas, is the GOES series.

reception and near-real-time fire information over Africa. However, when the documentation of the fire activity does not require long-term and continuous coverage, and when near-real time is not an issue, other sensors, as mentioned above, can provide a valuable contribution to practical studies.

8.4.2.3 Product Interpretation

There are several points that are important to take into account when interpreting and using active fire products from AVHRR data. Most of them are linked to the intrinsic characteristics of the satellite platform and its sensor. Detection algorithms are usually set to minimise the number of false detections. Consequently, some fires will also be missed. The main points to understand are described below:

- *Fire and pixel size.* AVHRR was not initially designed to detect fires. The AVHRR signal over an active fire saturates quickly, and thus does not vary very much between small and large fires. Consequently:
 - Very small fires are not detected. Pixel size conditions the minimum area that has to be burning to have a signal detectable from the satellite. Belward et al. (1993) demonstrated that a bush fire, with a burning front as small as 50 m, could be detected by AVHRR 1x1 km pixel.
 - A pixel detected as fire could represent different situations.
 - There could be one or several active fires in the area covered by the pixel, or the pixel area could all be covered by a large fire front, of which the pixel would only be a part.
- *Location accuracy.* The location of a fire can only be given within a variable range, which for AVHRR typically varies between 1 and 3 km. The term “fire location” refers to the central latitude and longitude of the fire pixel. It is easy to understand that – depending on the fire size and the pixel size as described above – the central point of the pixel may not exactly represent the position of the fire. In addition, errors can also come from the actual geographical registration accuracy of satellite image in itself.
- *Timing.* Only those fires that are active at the time of the satellite overpass will be detected. Those fires starting after image acquisition will not be detected until the next image, or missed if they are extinguished prior to the acquisition of the next one. While this can be a constraint for fire fighting, because the NOAA satellite passes in the afternoon, local time, corresponding to high fire activity, active fire products will be representative of the general fire activity.
- *Clouds.* Although AVHRR channel three can see active fires through smoke and thin clouds, fires under thick clouds are not visible from the satellite.

Finally, it is important to note that products should be field validated where possible. However, it is difficult to validate remote sensing products because of scale issues, as well as the cost associated with exhaustive validation campaigns. Experience shows that current algorithms perform well, and

the existing imprecision is usually greatly outweighed by the advantages of remote sensing observations (large area, repeated coverage, etc.). However, users should always be aware of these issues and, when possible, adjust algorithms for their own region.

8.4.3 Burned Areas

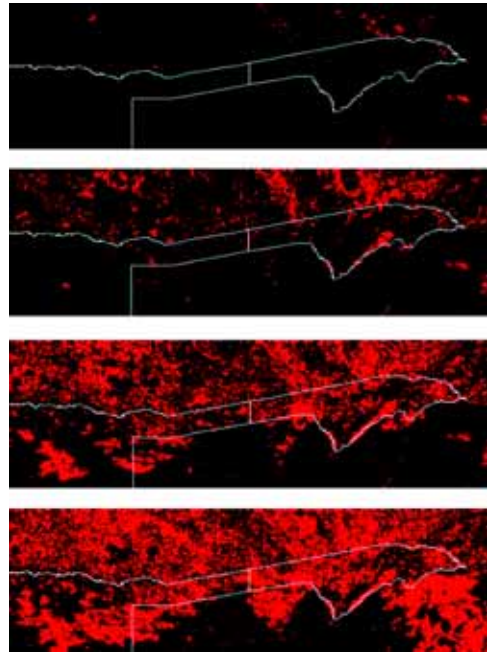
8.4.3.1 Burned Area Product Principles

Burned areas are detected from remotely sensed data based on three main changes in surface properties following fire:

- Vegetation is removed.
- Combustion residues are deposited.
- During the day, the burned surface is hotter than surrounding vegetation, with a maximum contrast in temperature occurring around mid-day.

As the above changes remain for some time after burning, a “memory” is held of the affected areas. This “memory” is unavailable to active fire detection, but enables burned areas to be mapped during entire fire seasons using relatively few remotely sensed images (Eva & Lambin, 1998). The main downside is that, at present, burned area detection methods are generally less automated than active fire-based methods.

The basic burned area product is an image, which shows burned areas in a different colour to unburned areas. Burned area products are usually provided in a standard map projection, so that the geographic coordinates (e.g. latitude/longitude) of any pixel are easily obtained.



8.7

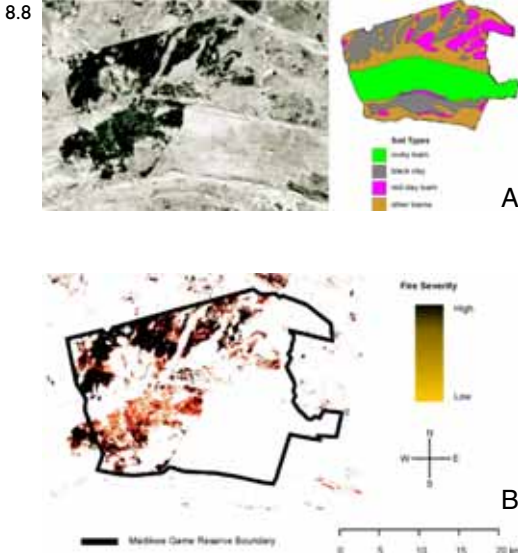
8.4.3.2 Burned Area Products in Fire Management

Integrated into a Fire Management Information System, burned area products are useful at all stages of the fire management loop:

Baseline data

Burned area products can provide important baseline information on fire regimes (i.e. frequency, season and intensity). *Fire frequency maps* are obtained by superimposing burned area maps for successive years. *Seasonal fire maps* are produced using several successive burned area products. Figure 8.7 shows a time series of burned area products for Caprivi, north-east Namibia, which includes parts of Angola to the north, Botswana

Figure 8.7. Burned area products, showing the progressive accumulation of burned areas during the 1996 fire season in the Caprivi and Kavango regions, north-east Namibia and surrounding areas. The products are based on NOAA AVHRR images of the area, which were acquired at regular intervals throughout the fire season.



Methods have also been developed to infer fire severity from the reflective properties of combustion residues (Jakubauskas et al., 1990; Thompson, 1993). Figure 8.8 (A) is an image of the Madikwe Game Reserve derived from Landsat TM images, and shows large, burned areas in shades of dark grey to black. A map of relative fire severity was derived from this image and is shown in Figure 8.8 (B).

Fire management

Both the block and patch-mosaic fire management strategies of prescribed burning require accurate fire records to help plan ignitions (Du Plessis, 1997; Brockett et al., 2001; Parr & Brockett, 1999). Burned area products are increasingly being used to provide this record (Du Plessis, 1997; Hetherington, 1997: 1998). Mapping burned areas as the season progresses also allows areas that burn naturally to be incorporated into ignitions planning. Burned areas products can also be of value to fire suppression teams. For example, an undesired active fire may not require immediate suppression effort if it is burning towards a large area already mapped as recently burned.

Monitoring and evaluation of management activities

The products can also help to answer management evaluation questions such as: How well did management fire lines stop fires (i.e., by overlay of burned areas and fire lines)? Have management efforts reduced the areas that burn each year; or – more generally – how well are desired fire regimes realised? By cross-referencing remotely-derived information on *actual* fire regimes with

to the south, and Zambia to the west (Trigg et al., 1997). It was produced using NOAA AVHRR images acquired at regular intervals throughout the 1996 fire season. These images could be used to produce seasonal fire maps by colour coding burned areas according to the time interval during which they were detected. The precision of seasonal fire maps (date-of-burn maps) is determined by the time interval between successive images.

Fire intensity and fire severity (i.e. the degree of vegetation change induced by fire) can often be inferred from the date and pattern of mapped burned areas. For example, homogenous burns occur late in the dry season and usually indicate high fire line intensity, whilst more patchy fires (early in the season) usually indicate lower fire intensities.

Figure 8.8. (a) An image of the area in and around Madikwe Game Reserve, made by applying multi-temporal principal components analysis to Landsat TM images, taken before and after a large part of the area burned in 1994. The burned area is clearly visible as a dark area surrounded by brighter unburned vegetation. (b) Map of relative fire severity in the burned areas apparent in the principal components image. In this landscape, soil type (see soil map inset) is the main determinant of patterns in vegetation communities, which is in turn coupled to their characteristic fire regimes through mutual feedback.

ecological information on *desired* fire regimes, it is possible to highlight areas where existing regimes are acceptable, or rather deviating, from the intention. This is a powerful tool for developing fire policies, modelling their outcomes and then formulating strategies, and for helping to direct fire management activities.

Refining policy

All the above are then used to refine fire management policies. Fire frequency maps can also help identify areas where high intensity fires are burning frequently, as foci for field visits to investigate the causes and the fire effects.

Burned area products

Figure 8.9 is a flow chart of the steps typically involved in preparing burned area products (although the flow may not be so linear). This procedure is important because one must choose the appropriate technique according to the product required. The steps are expanded below.

- *Specify format of the burned area products.*
It is first necessary to choose which burned area products are needed in order to provide information required by management.
- *Decide on appropriate scale of mapping.*
Scale includes the dimensions of the area that is to be mapped, the level of detail (or spatial resolution) that is required, and how often the map needs to be updated, (i.e. the temporal resolution of the map). In Figure 8.7 the large area involved (145 000 km²) meant that small-scale mapping was the only option. In Figure 8.8, the area is much smaller at

604 km², thus large scale-mapping was attainable. The decision on the level of detail required for the map (spatial resolution) should be made carefully in relation to management needs. For example, block burning (Du Plessis, 1997; Stander et al., 1993) results in relatively large and homogeneous burned areas (Parr & Brockett, 1999; Brockett et al., 2001). High detail is generally not crucial to map these adequately, and even AVHRR imagery (with a 1.1 × 1.1 km pixel size) can often yield more accurate results than the usual field-based method of driving block perimeters. An interpretation of a comparison between burned areas mapped using AVHRR and TM also found that AVHRR was mapping fires at the scale of the field mapping undertaken by section rangers in the Kruger National Park (Hetherington, 1997; 1998). Data from sensors such as AVHRR (which can be accessed freely each day using a relatively low cost, PC-based receiver) and MODIS (data freely available over the Internet) become attractive choices. In contrast, fire that is prescribed using a patch mosaic system results, in numerous small but ecologically important burned areas (Parr & Brockett, 1999). Higher detail is needed to resolve these accurately, so images from sensors, such as SPOT-HRVIR and Landsat-TM are required. The downside is the much higher costs for covering smaller areas, which means that management will want to know the minimum number of images needed to map burned areas each season. The regularity with which images need to be obtained

8.9

1. Choose format of burned area product, for example:
 - Fire frequency (annual maps post-fire)
 - Date-of-burn maps (multi-temporal maps during fire season)
 - Fire intensity
 - Fire severity



2. Decide on appropriate scale of mapping:
 - Dimensions of area to be covered
 - Level of detail (spatial resolution)
 - How often (temporal resolution)



3. Select suitable source of imagery: SPOT HRVIR, Landsat TM, MODIS, SPOT VGT, AVHRR, etc.



4. Decide on appropriate method for mapping burned areas and apply it to the imagery to produce the desired product.



5. Assess map accuracy using reference data collected at representative locations.

depends on the product type and the temporal spacing of images required to ensure that burned areas are not missed.

- *Select suitable source of imagery*

Having weighed up the requirements of product format and scale, the image data source can be chosen. In making a choice, it is important to also confirm that this source will be adequately sensitive to the parameter of interest, perhaps via a pilot study or by conducting a literature review. It should also be remembered that, for monitoring purposes, it is important that scale is maintained. Hence budget constraints are very important considerations in making a final decision.

- *Decide on appropriate method for mapping burned areas.*

Having chosen an appropriate data source, the accuracy of burned area mapping will depend on the method used. Compared to active fires, burned areas contrast relatively weakly with unburned vegetation, and so it is important to choose a robust method that is sensitive to changes caused by burning, yet insensitive to changes from other sources of variation (Trigg & Flasse, 2001). In general, burned areas that are smaller than the ground area covered by one image pixel cannot be detected.

Burned areas are often obvious visually to an image interpreter because of the superior ability of the human mind, relative to current computer-based methods, in recognising spatial patterns. Edwards et al. (1999) compared five burned area mapping techniques and found on-screen manual digitising to be more accurate than automated image processing techniques. However, the patchiness of burned areas makes manually digitising them very tedious and subjective. Further considerations of time, practicality, objectivity and ability to repeat, make automated analysis techniques preferable for extracting burned areas from remotely sensed imagery. Most image processing techniques operate in the *spectral domain*, that is, they use differences in the amount of energy received from burned and unburned areas in the different spectral bands available to discern between the two cover types. Visual interpretation uses both the spectral domain (manifested as variations in image brightness or

Figure 8.9. Flow diagramme showing the main steps and considerations in the preparation of burned area products.

colour) and the spatial domain (variations in pattern and texture). Multi-spectral imagery typically includes bands in the near- to thermal-infrared, which contain more spectral information indicative of burned areas than the visible channels (Pereira & Setzer, 1993; Pereira et al., 1999a; Trigg & Flasse, 2000). For visual interpretation, any combination of three bands may be displayed, for example using the red, green and blue colour guns of a computer screen, although no more than three bands may be displayed at once. On the other hand, there is no practical limit to the number of spectral bands that can be simultaneously processed by computer-based methods to detect burned areas.

Computer-based detection methods are usually based on identification of one or more of the physical changes mentioned in the introduction to this section:

- Methods sensitive to vegetation removal usually use vegetation indices (VIs – simple algebraic combinations of more than one band), whose values tend to decrease sharply after burning, providing a basis for detection. Historically, NDVI was the most commonly used VI for detecting burned areas, and it has been used on all fire-prone continents, although numerous inherent limitations have now been described. More recent VIs such as GEMI (and its variants) and atmospherically resistant VIs (ARVIs) are increasingly used in preference to NDVI (Pereira, 1999; Miura et al., 1998). VIs are most useful for detecting burned areas if primarily photosynthesising vegetation burns (e.g. in pine and evergreen forests). However, in areas such as grassland, shrubland and deciduous woodland, widespread vegetation senescence can occur prior to burning, which can decrease the accuracy of VI-based detection (Trigg & Flasse, 2000). Certain land management activities that alter vegetation abundance (e.g. tree felling) may also be mistaken for burning using VIs.
- Burned surfaces covered by char combustion residues usually appear much darker than unburned vegetation, particularly in the near-infrared (NIR), providing a very good basis for detection (Trigg & Flasse, 2000). However, this basis is short-lived in areas where char is removed rapidly by the wind and rain, making the burned area brighter and less distinguishable from unburned vegetation. Other cover types, such as water, may be indistinguishable from burned areas in the NIR, and so bands at other wavelengths are often needed to help resolve this confusion. NIR bands are less discriminating in areas where more efficient combustion results in bright ash residues that contrast less strongly with unburned vegetation.
- As one might expect, methods that detect burned areas as hot surfaces use bands in the thermal infrared (TIR). While generally robust, thermal-based detection is not possible at times or in places where surface temperature exceeds the upper limit that can be measured by a particular sensor. For example, AVHRR band three images are useful for detecting burned areas, but only if surface temperatures stay below approximately 51°C, i.e. the highest measurable temperature.

In Namibia, un-shaded surface temperatures usually exceed this limit around mid-day from August and October, rendering AVHRR band three images unusable. New sensors, such as MODIS, can measure much higher temperatures and so avoid this problem of “saturation”. The utility of night-time thermal imagery is limited due to the poor thermal contrast between burned and unburned areas found at night. Another constraint is that smoke plumes present cool features that can conceal underlying burned areas at long-thermal infrared wavelengths.

In practice, burned area detection methods usually combine spectral bands to provide sensitivity to one or more of the fire-induced changes. Examples include multi-spectral image classification, principle components analysis (Hudak et al., 1998), and spectral indices designed specifically to detect burned areas (Trigg & Flasse, 2000). Many of the available methods are reviewed in Pereira et al. (1999b) and Koutsias et al. (1999).

Detection methods can also be grouped depending on how many images they use. *Single-image* detection is based on the assumption that all burned areas will be distinguishable in the spectral domain on just one image. Although one image is quick and cheap to obtain and process, several other cover types, such as shaded slopes, water bodies, urban areas and bare soils may be indistinguishable from burned areas on imagery taken on a single date. Some of the confusion may be resolved by using spectral information from all of the available spectral bands in the image, sometimes in conjunction with sophisticated

image transformation techniques (e.g. Koutsias et al., 1999).

Another approach, *multiple-image* detection, is based on the assumption that a fire-affected area will appear spectrally different on a post-fire image compared to its appearance on an image taken before the fire. Due to the large changes caused by fire, methods that look for fire-induced changes between dates (“change detection” methods) usually detect burned areas more accurately than single-date methods (Thompson & Vink, 1997; Hudak et al., 1998). For example, urban areas and bare soils can appear similar to burned areas on a single image, but will change little between image dates, in discernible contrast to most fire-induced changes.

Multiple-image methods, however, require stringent preparation of imagery. Images must be geographically registered accurately to one another (“co-registered”) to avoid “burned areas” appearing between dates that are really just due to inaccurate registration. Co-registration of images becomes less accurate with decreased spatial resolution. Images must also be radiometrically inter-comparable, i.e. the same band, band combination or index from the same sensor should be used for each image date.

Adjustments may also be necessary to normalise the sensitivity of each image prior to their comparison to try to prevent changes in viewing geometry and atmospheric conditions between dates from generating spurious changes in pixel values that could be mistaken for burned areas (Viedma et al., 1997). Other disadvantages are that a minimum of two images per detection halves the chance of obtaining a cloud-free

product and doubles the cost over single-image techniques.

8.4.3.3 Other Considerations Relevant to All Methods of Detection

Obscuration of burned areas

Smoke is relatively opaque at visible wavelengths, can obscure burned areas at long-thermal infrared wavelengths, and has a small effect at NIR wavelengths, all of which can complicate burned area detection. However, at certain MIR wavelengths, even optically thick smoke plumes are transparent (Miura et al., 1998). MIR-based detection is therefore useful in areas where thick smoke is present for much of the burning season, as is the case over much of Africa.

Thick cloud obscures the surface at visible to thermal wavelengths and can confound remote detection of burned areas. This is a particular constraint when mapping large late dry-season fires, which can be obscured by cloud. In such cases, field mapping is still necessary.

Dense tree canopies can “hide” fires that are burning in the grass-shrub layer below, as was noted in the Hluhluwe-Umfolozi Game Reserve (Thompson, 1993).

Post-fire regrowth and greenup

Regrowth of vegetation following burning can also confound detection. This can be a major limitation in places where greening up begins within a few days of burning (e.g. in Ivory Coast – Belward et al., 1993), or if pre-cured grass burns early in the season and has greened up before an image is obtained. This affected the accuracy of mapping

of early season (pre-curing) fires in Pilanesberg National Park, South Africa in 1996 (Thompson & Vink, 1997), with some small fires left detected using a multi-temporal approach.

Green up poses less of a constraint in areas where it is delayed until the onset of rains, as is the case over much of Namibia, parts of South Africa and Botswana.

Soil moisture

High soil moisture levels and consequently patchy (low severity) fires can also confound detection in certain circumstances, e.g. Pilanesberg National Park in 1997 with late season rains (Thompson & Vink, 1997). Wet soils can be much darker than dry soils, and may be misclassified as burned areas.

Threshold variability

Variations in viewing atmospheric and surface conditions at different places and times mean that it is not usually possible to use the same fixed numerical thresholds to classify pixels as burned or unburned. Appropriate thresholds may be chosen using field validation data (but these are often lacking), by visual interpretation or using statistically-based techniques. Visual determination is usually superior to statistical methods, because it takes advantage of the superior pattern recognition ability of the human mind. For example, Salvador et al. (2000) attempted several objective techniques for detecting burned area thresholds, but found all to be inferior to visual assessment. Interactive methods, however, require the analyst to have a good knowledge of visual interpretation of burned areas from multi-band imagery. Research is ongoing to develop fully automated techniques,

but it is likely that visual checking of burned area products will always be important.

Assess map accuracy using reference data

It is a good idea to check product accuracy by gathering a representative sample of independent reference data on burned and unburned areas, with which to validate the burned area product. Establishing map accuracy gives decision makers confidence in using the remotely sensed products, and can identify areas where the mapping method needs further improvement. Congalton and Green (1999) provide a review of the main methods used to assess the accuracy of remotely sensed data.

The upsides

Having discussed the pitfalls, it is important to state some of the upsides of burned area mapping using remote sensing. Existing semi-automated methods (e.g. Flasse, 1999; Salvador et al., 2000), if chosen and applied with care, can rapidly and cheaply deliver products at sufficient accuracy for fire management. In fact, since it is only required to classify two classes (burned and unburned), product accuracy should routinely exceed, for example, the accuracy of remotely derived vegetation maps (since classification accuracy generally increases as the number of classes decreases [Sannier, 1999]). Several studies have found remote mapping of burned areas to be much more accurate than ground-based mapping for capturing the patchy nature of burned areas – including the recording of unburned “islands” within larger burns. For example, in the 48 000 ha Pilanesberg National Park, Thompson and Vink (1997) found

that field maps overestimated by 8500 ha (or approximately 17%) the actual area burned, resulting in an over-estimate of 39.5% compared with satellite-derived burned area maps. Section 8.7 will give example of use of burned area products in operational activities.

8.4.4 Vegetation Monitoring

8.4.4.1 Vegetation Products in Fire Management

Vegetation monitoring provides important information for understanding fire behaviour, including ignition, growth and rate of spread (Cheney & Sullivan, 1997), and is therefore crucial to help land managers optimise both fire prevention and fighting activity. Preventive actions in the USA, Europe, Africa and Australia include the use of prescribed fires.

In grassland and savanna with seasonal drought, fires during the dry season are limited by grass fuel availability, and grass productivity is in turn a function of soil moisture availability from the preceding rainy season (Scholes & Walker, 1993). Thus, fire frequency declines as precipitation declines through an indirect yet strong relationship. In forests, fuels accumulate over dekadal time scales, and fire frequencies are much lower, with fires occurring during episodic droughts. In grassland, savanna or forests, fire frequency and intensity depend on ignition sources, fuel characteristics (e.g. distribution, compaction, types, moisture content, accumulation and flammability [see Trollope, 1992]), and the vegetation landscape mosaic (Christensen, 1981). Shifts in fire frequency lead to changes in vegetation structure,

which in turn modify the intensity of subsequent fires (Kilgore, 1981).

The important vegetation characteristics to be taken into account in fire management are therefore: Fuel load (influencing fire intensity), moisture content (influencing both fire ignition and spread), continuity (influencing fire spread) and height (influencing height of flames and hence difficulty of suppression).

Fuel characteristics may be measured in the field, but such measurements only represent local conditions at a few locations. Remotely sensed data provide information at landscape, regional and global scales, and are therefore more useful for land managers.

8.4.4.2 Vegetation Monitoring Systems

Several different sensors currently on board Earth Observation System satellites are used to monitor vegetation in three different portions of the Electromagnetic (EM) spectrum.

- *Visible to shortwave infrared* (0.40–2.50 μm , previously defined also as visible, NIR, SMIR and LMIR). Vegetation reflectance in this portion of the spectrum provides information on vegetation biophysical parameters such as chlorophyll, physiological structure and leaf cellular water content (Tucker, 1980). Chlorophyll absorbs the red and blue elements of the EM spectrum, internal leaf structure makes vegetation highly reflective in the near-infrared and leaf cellular water absorbs radiation in the shortwave infrared. Satellite band combinations of different regions of the EM spectrum (also called vegetation indices)

emphasise the spectral contrast between the different regions of the EM spectrum and allow hidden information to be retrieved. Vegetation indices are empirical formulae designed to produce quantitative measures, which often relate to vegetation biomass and condition (Gibson & Power, 2000; Verstraete & Pinty, 1996). The most commonly used vegetation index is the Normalised Difference Vegetation Index (NDVI):

$$\text{NDVI} = \frac{(\text{NIR} - \text{red})}{(\text{NIR} + \text{red})}$$

where NIR is the reflectance measured in the near infrared channel and red the reflectance measured in the red channel; the higher the NDVI value, the denser or healthier the green vegetation. Visible and near-infrared channels are available on most optical satellite sensors including NOAA-AVHRR, EOS-MODIS, SPOT-VEGETATION, SPOT-HRVIS, LANDSAT-TM, and LANDSAT-MSS. Other indices, such as the SAVI, TSAVI, ARVI, GEMI (see Flasse & Verstraete, 1994, for more details), have been developed to identify the presence of vegetation and to be less affected by perturbing factors, such as soil colour and atmospheric contamination.

To advance further the performance of such spectral indices, a method has now been proposed by Verstraete and Pinty (1996) to create an optimised index for specific sensor characteristics. In any case, it is important that users carefully choose the appropriate index to best respond to the requirement of their work. Lidar is an active remote sensing

system based on laser altimetry principles that operates in the near-infrared portion of the spectrum, where green vegetation is highly reflective. Lidar accurately measures tree heights and has been used to estimate forest canopy volume, which has been shown to be a good indicator of biomass and leaf area in high biomass forests of the US Pacific Northwest (Lefsky et al., 1999b). No satellite lidar systems have yet been launched, but the Vegetation Canopy Lidar (VCL) satellite is currently being constructed.

- *Thermal infrared* (6.0–15.0 mm). Emittance in this portion of the EM spectrum provides information on the thermal properties of vegetation cover, such as sensible heat. Heat measured by satellite sensors is used to estimate evapotranspiration of vegetation canopies, which can be a good indicator of water stress (Moran et al., 1994). Thermal infrared bands are available on sensors such as NOAA-AVHRR, METEOSAT, and LANDSAT-TM.
- *Microwave* (0.1–100 cm). Active and passive microwave approaches have been developed to sense soil water content, which can be highly relevant to vegetation monitoring (Du et al., 2000). Passive microwave sensors provide information on the thermal properties of water (Schmugge, 1978). Passive sensor SSM/I is currently available on the Defense Meteorological Satellite Program (DMSP) platform. Active microwave sensors provide information on the dielectric constant, which may be related to vegetation water content (Moghaddam & Saatchi, 1999). Active sensors currently available include RADARSAT and

ERS-2, and ENVISAT-ASAR from October 2001.

8.4.4.3 Operational Vegetation Products

The main vegetation products useful to fire management are:

- *Fuel load*. Estimation of biomass is performed using optical sensors. Biomass maps were derived in the grassland regions of Etosha National Park, Namibia, using NDVI computed from NOAA-AVHRR images (Sannier et al., 2002). Similarly, Rasmussen (1998) estimated net primary production in Senegal. However, these studies are spatially limited and more work is required on refining the relationship between biomass and the NDVI for different vegetation communities. Lidar data may one day prove useful for measuring and monitoring forest biomass, but are still mostly unavailable.
- *Vegetation moisture content*. Operational estimation of vegetation water content is performed using optical and thermal infrared sensors. The use of radar sensors to monitor vegetation water content requires further research before it will be operational (e.g. Moghaddam & Saatchi, 1999).

Three methods are used to estimate vegetation water content. The first method uses the Normalised Difference Vegetation Index (NDVI) to estimate live vegetation chlorophyll and moisture content (Burgan, 1996). The NDVI is used to compute a Relative Greenness Index (RGI), which is incorporated with weather data to define a Fire Potential

Index (FPI) (Burgan et al., 1998). The FPI is computed for assessing forest fire hazards in the Mediterranean climate region of southern California (USA) (<http://edcsnw3.cr.usgs.gov/ip/firefeature/firepaper.htm>).

Similarly, the Fire Potential Index has been adopted by the Natural Hazards project of the Space Application Institute, Joint Research Centre (Ispra, Italy) to evaluate forest fire risks in Europe (<http://natural-hazards.aris.sai.jrc.it/fires/risk/>). However, Ceccato et al. (2001a) recently showed that the relationship between degree of curing and vegetation moisture content is not applicable to all types of vegetation.

The second method estimates the moisture content through the measurement of evapotranspiration, an indicator of vegetation condition. Evapotranspiration, as measured by thermal sensors, may be estimated with several indices: the Crop-Water Stress Index (CWSI) (Jackson et al., 1981), the Stress Index (SI) (Vidal et al., 1994), and the Water Deficit Index (WDI) (Moran et al., 1994). However, it has been shown that many species may reduce evapotranspiration without experiencing a reduction of water content (Ceccato et al., 2001a).

The third method is based on direct measurement of vegetation water content and uses the absorption property of water in the shortwave infrared (spectrum between 1.13 mm and 2.50 mm). Using a combination of the shortwave infrared and infrared wavelengths from SPOT-VEGETATION, a Global Vegetation Moisture Index has been

created to measure directly vegetation water content (Ceccato et al., 2002a). This method is currently being tested for fire management applications (Ceccato et al., 2002b).

- *Vegetation continuity and density.* High-resolution satellites are needed to characterise the spatial structure of the vegetation canopy. Hudak and Wessman (2001) have shown that a textural index of high-resolution imagery serves as an accurate indicator of woody plant density in semi-arid savanna.
- *Vegetation height.* Estimation of vegetation height is still at a research stage. Synthetic Aperture Radar (SAR) studies are being developed to estimate vegetation height (Sarabandi, 1997), but are not yet operational. Lidar provides direct, accurate measurements of canopy height but are currently limited in spatial extent and availability (Lefsky et al., 1999a).

8.4.5 Rainfall Estimation

8.4.5.1 Derivation of Rainfall Estimates

Rainfall is normally measured using rain gauges. However, the network of rain gauges may be sparse in those areas affected by fire. Satellite observations are used in combination with, and to augment, rain gauge data. Satellite data provide a spatially complete, uniformly distributed coverage that allows better estimation of rainfall where rain gauges are infrequently and irregularly sited.

Meteorological satellites in geo-stationary orbit (i.e. an orbit where the satellite appears fixed at the same point in the sky) are able to collect images of a large area frequently. For example,

the Meteosat satellite collects an image of the whole of Africa and Europe every 30 minutes. Similar satellites are available for other parts of the Earth. The frequency of images collected by these satellites is important, as it allows rain clouds to be located and tracked, which is vital data for producing accurate rainfall estimations. Data from polar orbiting satellites (which move across the sky) can be used to estimate rainfall (e.g. using passive microwave data) but these data are available much less frequently for each location on the ground.

Geo-stationary satellite rainfall measurements are particularly appropriate for areas where rainfall comes mainly from convective clouds. Convective clouds are formed when small warm lumps of air (called thermals) rise up to produce clouds. On meteorological satellite images these clouds appear firstly as small and round and, as they grow, become colder. They cool down as they rise and thicken into storm clouds. The temperature of the cloud top can easily be measured (both day and night) using the thermal infrared waveband data. It is possible to predict whether particular clouds will produce rainfall because the colder (and thicker) the cloud, the more likely it is that rain will fall. The duration of the cold cloud in any particular location can be measured quite precisely as images are available so frequently. A simple linear relationship between cold-cloud-duration (CCD) and the amount of rain produced is used as the basis for a first indication of the quantity of rainfall. Local rain gauge data is used to calibrate the rainfall estimation for each location. This technique is called the cold cloud precipitation method.

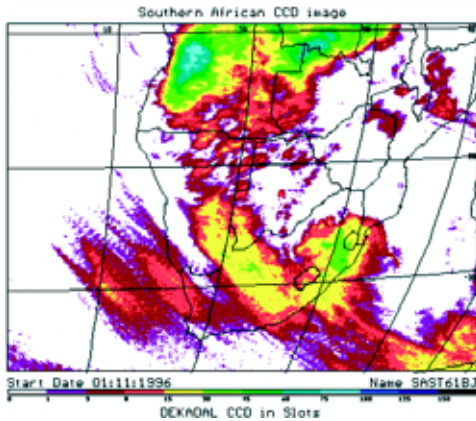
The cold cloud precipitation method does not work so well for estimating rainfall from other types of cloud. For example, layer (stratiform) clouds form when air rises consistently, either by night-time cooling or by clouds associated with weather fronts. For these types of clouds the relationship with rainfall is more complicated. Hence, cold cloud precipitation method of rainfall estimation works well in the tropics where most of the cloud is convective, but less well in mid and high latitudes where other types of cloud are dominant.

The rainfall estimations are usually built up over a period of approximately ten days, called a "dekad" (this is a standard reporting period for meteorological data). There are three dekads in each calendar month. The first dekad of each month begins on the 1st; the second dekad begins on the 11th and the third dekad begins on the 21st (and hence will vary in length depending on the particular month). Figure 8.10 provides an illustration of dekadal CCD.

8.4.5.2 Sources of Rainfall Estimates

The TAMSAT (Tropical Applications of Meteorology using SATellite and other data) group, at the University of Reading (UK) researches the use of satellite imagery for estimating rainfall. More details of the cold cloud precipitation method and how it can be applied is given in Milford et al. (1996). They have produced a Rainfall Estimation Workbook (Grimes et al., 1998) to introduce practical rainfall estimation techniques. An extensive list of publications and the latest on-line dekadal rainfall estimate is provided on their website at <http://www.met.rdg.ac.uk/tamsat/>.

8.10



The United States Agency for International Development (USAID) Famine Early Warning System (FEWS) produces estimates of accumulated rainfall to assist in drought monitoring efforts in sub-Saharan Africa. Their methodology is based on the cold cloud precipitation method, but incorporates some other data where they deal better with non-convective rainfall (Xie & Arkin, 1997; Herman et al., web publication). They use numerical models to produce wind and relative humidity information and take into account the contribution of orographic rainfall (where different rainfall patterns are produced by the structure of the terrain). Satellite-passive microwave rainfall estimations are also incorporated.

FEWS rainfall estimation (RFE) data, including daily, dekadal and historical archives, are available for sub-Saharan Africa from the Africa Data Dissemination Service (ADDS) website at <http://edcintl.cr.usgs.gov/adds/adds.html>.

ADDS also hosts other data sets, including satellite-derived dekadal vegetation information,

agricultural statistics and digital map data. Rainfall charts can be viewed on-line or downloaded. Software to store, analyse and display rainfall data can also be downloaded.

8.4.5.3 Rainfall Data in Fire Information Systems

Rainfall estimations can be produced for finely gridded areas, e.g. 5 x 5 km areas, but are often used as summaries over political or physical regions, for example, countries or catchments. Statistics can include total, mean and standard deviation of rainfall in millimetres, area of rainfall coverage within a region, etc. The rainfall data can be combined with other data to produce further information, for example, hydrological modelling or a fire information system.

Rainfall maps can be used to inform management, for example, recent rainfall could be taken into account when deciding the timing of prescribed burns (Carlson, 2001).

Rainfall estimation can also be integrated with other data, for example, as an input to fire risk assessment (Aguado et al., 2001). The rainfall information is incorporated in estimation of vegetation moisture content, which can then be combined with fuel data for assessing fire risk.

8.5 IMPLEMENTING REMOTE SENSING IN A FIRE MANAGEMENT CONTEXT

This section looks briefly at some of the resources typically required to run a small remote sensing component to contribute to fire management. Data produced by any remote sensing activities should be integrated into a fire management information system so that, through the combination

Figure 8.10. Example of a Dekadal Cold Cloud Duration (CCD) image (one slot equates to 30 minutes).

of data from various sources, more information can be extracted to better support management decision-making.

A range of situations could occur and some fire management teams may have access to their own remote sensing group or government-run remote sensing resources. Many others may find some existing local expertise in remote sensing, e.g. a local consultancy, scientific institute or university who could assist in the setting up of a remote sensing group, provide training or even be contracted to do the work. Alternatively, an in-house specialism could be developed.

It is important to have a general idea of what is wanted out of any remote sensing endeavour so that sensible levels of resources can then be allocated to achieve the desired outputs. A remote sensing expert should work with management to identify areas where remote sensing can contribute and help design an overall remote sensing strategy. The following are some considerations for those who want to set up and run a remote sensing component for fire monitoring and management.

8.5.1 Skilled Personnel

The person running the component should have a combination of remote sensing skills and field experience (perhaps in fire or vegetation ecology), or at least demonstrated aptitude and a willingness to learn new skills. He or she should have some input to design of a remote sensing strategy, decide which imagery will be used to obtain the information, and how often, and choose and implement the methods to extract information. The person should make every effort to

assure quality control at all stages, including assessing the accuracy of final products wherever possible.

Once procedures are in place for preparing operational products, there will be routine image processing and data input tasks to complete. These tasks are essential to maintain a fire management information system and allow use of the latest information.

It is also important to have a person around who completely understands how the information system operates and can draw awareness to and help users to exploit the potential of the system. These functions are best served in-house. Hence, the most appropriate person may be someone with local knowledge of fire conditions, and the required outputs of a fire management information system. In most cases, computer literate staff can also be trained to maintain an information system.

8.5.2 Access to Relevant Information

Staff should ideally have access to publications on remote sensing, land mapping, fire ecology and other relevant information. Easy access to up-to-date literature is especially helpful in selecting appropriate methods to deliver particular information products and in avoiding common mistakes. Collaborative research with local and international scientific institutions can also help in product development.

8.5.3 Infrastructure

Office space is required for in-house remote sensing, and adequate remote sensing hardware and software must be acquired. Image processing

and Geographic Information System (GIS) tools allow a fire information system to be built up with the objective of supporting operational fire management.

Computer hardware will typically include at least one PC with a high-speed processor, large hard disk and lots of memory. A large monitor is also useful, allowing images to be seen in reasonable detail without the need for excessive zooming.

There will also be data archiving and retrieval capacity, e.g. CD read/writers are currently a very attractive option, since most receiving stations now provide remotely sensed images on CD, due to the low costs for this media. A colour printer is essential for the presentation of the various products, while a Global Positioning System (GPS) receiver can be very useful in collecting accurately located field data for plotting on geo-referenced images. A digitising table is also useful so that information held on topographic and other paper maps can be integrated with remotely sensed images and other data in a GIS.

Image processing software provides the tools required to pre-process imagery into usable form (e.g. to correct and calibrate raw imagery and transform it to a standard map projection) and to develop and apply algorithms to process data into information products. They also have sophisticated tools for investigating, displaying and enhancing the appearance of imagery.

GIS software is also required for a sophisticated information system that allows integrated

analysis of many layers of spatially registered information. GIS tools can allow remotely sensed products to be analysed in the context of any other geo-located information held by management, such as maps of infrastructure, administrative boundaries, planned ignition points, fire history and maps made in the field (e.g. vegetation type, fire severity, etc.).

Spatial models can be built up through the arithmetical combination of information in the different layers. For example, fire danger might be estimated by combining remotely sensed indicators of vegetation state and standing biomass with maps of roads and population centres and synoptic meteorological data.

8.5.3.1 Adequate Budget to Maintain the Information System

As well as personnel and initial set-up costs for hardware and software, the budget should include allocations for recurrent expenses, such as image data costs and additional data acquisition. Maintenance and upgrade costs for hardware and software, and replacement of consumables, must be considered too. Fieldwork is necessary to validate remote sensing outputs, so a budget for transport (and maybe equipment) should be available. It should be remembered that, for monitoring purposes, it is important to maintain the scale of data and the frequency of acquisition, so that quality and consistency of information products are maintained. Hence, budget constraints are very important in developing an operational remote sensing strategy.

8.6 EXAMPLES OF APPLICATION OF REMOTE SENSING PRODUCTS IN FIRE MANAGEMENT IN AFRICA

8.6.1 South Africa

The use of remote sensing technologies for fire management in South Africa can be divided into three basic application areas – namely, post-event burned area mapping (including associated fire intensity / severity analysis), active fire monitoring, and biomass estimation (in terms of fuel loads and potential fire risk assessment) – and are primarily concerned with the fire-prone savanna, grassland and fynbos biomes.

Post-event burned area mapping is arguably the most common application area, and has generally been conducted as a parallel research orientated activity in support of more operational, traditional field-based mapping. Many of the larger protected areas in the savanna biome have tested this kind of image-based fire mapping with a fair degree of success, e.g. Kruger National Park (Hetherington, 1997; 1998), Pilanesberg National Park (Thompson & Vink, 1997), Madikwe Game Reserve (Hudak et al., 1998), Mkuze Game Reserve and Hluhluwe-Umfolozi Game Reserve (Thompson, 1990; 1993).

Of key significance in many of these projects has been the obvious improvement in both the accuracy of individual burn area delineation, and the identification of small isolated non-burned “islands” that are often missed during more generalised field-mapping. For example, field-mapped estimates of total fire extent differed from image derived estimates by 50.4 %, equivalent to 4252 ha (4.5 % of total reserve area) in a

study completed by Thompson (1990; 1993) in Hluhluwe-Umfolozi Game Reserve (although it was noted at the time that under tree canopy fire scar extents were difficult to define on the imagery). Similar results have been reported for studies in Pilanesberg National Park, where field maps over-estimated the total burned area by 8500 ha (or 17% of the total reserve area) (Thompson & Vink, 1977). In this case field estimates were 39.5% higher than the satellite-derived estimate. In general, these historical fire-mapping exercises have used high resolution Landsat or SPOT multispectral imagery, for detailed mapping at scales in the order of 1:50 000 to 1:75 000.

Image classification problems tend to arise, as would be expected, when the image acquisition date is significantly different from the burn event date, especially if post-fire regrowth or green-up of the vegetation has occurred in the interim period. Additional classification problems can also be experienced if the prevailing environmental conditions at the time of the burn did not result in a clean burn with a clearly definable extent. The compilation of end-of-fire season fire scar maps for the Pilanesberg National Park for the past several years has indicated that no single image processing technique or algorithm is optimal for all conditions (especially if it is necessary to use sub-optimal imagery in terms of acquisition date in relation to actual fire event or precipitation patterns). Rather a range of data processing techniques are necessary to cover all possible conditions. For example, post-event fire scar mapping for the years 1994 to 2001 in Pilanesberg has involved the use of both single and multi-date

8.11



imagery, derived indices, simple-level slicing, isodata clustering models, and principal component analysis to map fire scars. In most cases, this has been based on Landsat Thematic Mapper imagery (bands three, four, five and seven), or closest SPOT equivalents.

Recent work used Landsat images to establish a fire history for Madikwe Game Reserve and surrounding farms, including Botswana's Kgatleng

area and southern district (Hudak & Brockett, *in press*). Fire history was derived from burned areas mapped from 22 annual fire maps from the period 1972 to 2002 (excluding 1974, 1975 to 1978, and 1981 to 1985).

Research has been conducted in terms of fire severity and intensity mapping using near-real time imagery, linked to internal fire scar characteristics. A key area of activity being studies linked

Figure 8.11. NASA ER-2 aircraft image of a prescribed SAFARI fire over the Timbavati Reserve. Higher confidences on the position of the flaming front and fire emission factors can be determined from ER-2 MODIS simulator data at a resolution of 50 m. Fire ground variables such as flame height, climate parameters and rate of spread are measured coinciding with TERRA and ER-2 overpasses.

to South Africa's contribution to the international SAFARI 2000 initiative. This has primarily involved the assessment of products derived from EOS-MODIS*, within the context of park fire management activities and the development of automated fire monitoring systems. Case studies are currently being conducted in both Kruger National Park and Madikwe Game Reserve, where to date over 80 fuel measurements involving prescribed burns have been recorded. The MODIS fire algorithms can be transitioned into an operational monitoring system to render accurate and timely information on the location, spatial distribution, intensity and timing of fires in South African conservation areas. These findings could support park management objectives that monitor and modify long-term fire management programmes in relevance to fire regimes.

This study involves validating MODIS burn scar data on a near-real time basis using co-located Landsat 7 ETM 30 m resolution fire maps, combined with field data on combustion intensity and completeness. Within the 2000 SAFARI field campaign, grey scale ash colour, biomass observations and field spectrometer recordings (using a hand held ASD radiometer) of burn scars were sampled, since ash colour is postulated as being a retrospective measurement of fire intensity (Stronach & McNaughton, 1989).

Post-fire burned area mapping in the fynbos biome is somewhat different from that in the savanna (or grassland) biome, since individual fire scars in fynbos can remain visible for many seasons after the actual fire event due to the slow regeneration of the local vegetation. Such conditions can make the temporal separation of inter- and

intra-year fire scars problematic, although Thompson (1990; 1993) reported that the use of within-scar NDVI difference was successful for age and sequence determination of historical fire scars in this area.

Satellite imagery received a major boost locally as an operational tool during the December 1999 – January 2000 wildfires in the Western Cape, which burnt vast tracts of mountain and coastal fynbos communities on the Cape Peninsular and West Coast. During this period a series of SPOT images was specially acquired to provide near-daily coverage of the fires and their rate of spread in, often inaccessible, mountains. Although this information was not used for true real-time fire management activities, it proved a useful tool for public-level media instruction as well as for post-event, disaster management assistance and planning.

Biomass monitoring is a key component of pre-fire risk assessment. Several case study examples illustrate the potential of remote sensing for this application, although, as with post-fire mapping, these are primarily research rather than operational level studies.

Studies in both the Hluhulwe-Umfolozi Game Reserve and Drakensberg mountains have indicated that pre-fire season predictions of potential fuel loads (tons / ha) can be achieved with a high degree of accuracy (i.e. $r^2 \gg 0.8$) in both savanna and grassland areas using Landsat and SPOT equivalent data. These are typically based end-of growing season NDVI-based biomass models, which have been calibrated with actual field-derived biomass data (Thompson, 1990; 1993; Everson & Thompson, 1993).

* In February 2000 Terra-AM, the flagship platform of NASA's Earth Observing System (EOS), began collecting what will ultimately become part of a new 18 year data set (Kaufman *et al.* 1998). The MODerate resolution Imaging Spectroradiometer (MODIS) onboard TERRA senses the earth's surface in 36 spectral bands and can provide daily coverage of South Africa at a nadir resolution of 250 m and 500 m in the visible to near-IR and 1 km resolution in the thermal spectral range.

More recently a similar research project looked at using coarser resolution 1 x 1 km SPOT VEGETATION NDVI products for determining end-of growing season fire risk along power transmission lines on a national basis, since wildfire combustion effects can result in transmission interrupts in some instances (Thompson & Vink, 2001).

Near-real time monitoring of local fire events is starting to become established as a viable technique at both local and national scales. For example, since November 2000 the ARC-ISCW* has been part of the World Fire Web (WFW), participating as the Southern Africa node. WFW is a global network of computers that detect active fires using daily NOAA-AVHRR satellite data. The network is co-ordinated by the European Union's Joint Research Centre (EU-JRC) in Ispra, Italy. The input data are daily NOAA-14 AVHRR afternoon passes (Ahern et al. 2000). Daily fire maps are compiled at each regional node and then made available in near real-time on the World Wide Web (WWW)**. The fire information can be downloaded in a text format giving latitude and longitude of each 1 km AVHRR pixel detected that contains a fire on that day. Improvements to the software will enable NOAA-16 imagery to be processed.

8.6.2 Namibia

8.6.2.1 Introduction

Namibia lies in the west of Southern Africa, bordering Botswana and South Africa to the east and south, the Atlantic Ocean to the west, and covering an area of approximately 824 000 km².

Large areas burn each year. Almost five million hectares burned in 2000, whilst in years of lower rainfall this figure is significantly lower (Le Roux, 2001). Excessive indiscriminate burning is having highly negative effects on some ecosystems, whilst in other areas, fire frequencies are more in equilibrium with requirements for the long-term stability of existing vegetation communities (Goldammer, 1998).

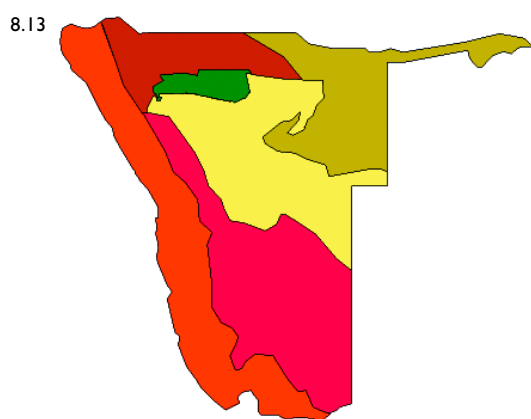
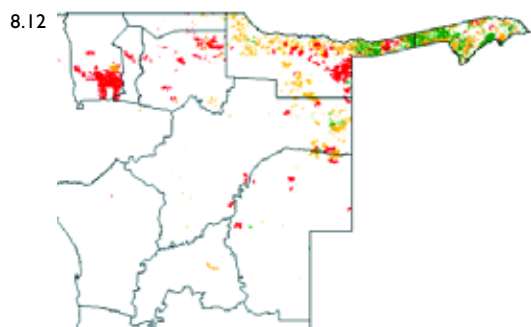
Fires burn during Namibia's severe dry season from April to October, mainly as surface fires that spread in the grass and shrub layer. Crown and ground fires occur over only limited geographical areas. The amount and connectivity of surface fuel is highly variable spatially and temporally, controlled by a severe rainfall gradient orientated in an approximately SW to NE direction. The most frequent, intense and extensive fires occur in the north and northeast, whilst fires occur infrequently in the south and west. Figure 8.12 shows a burned area map of the fire-prone areas of Namibia (derived from remote sensing) and demonstrates the general increase in the size and extent of burned areas from SW to NE. Lightning ignited fire is the most significant natural cause, but accounts for only a small percentage of all fires. The majority of fires are anthropogenic, either set deliberately or accidentally (Goldammer, 1998).

8.6.2.2 Fire Management Issues in Namibia

Figure 8.6.2b shows the six fire regime zones of Namibia (Trigg & Le Roux, 2001), as a framework for describing fire management issues in Namibia. In zones 1 and 2, low rainfall means that fires

* Agricultural Research Council: Institute for Soil, Climate and Water. ARC-ISCW (Pretoria), houses a fully calibrated NOAA-AVHRR 1 km data set for Africa south of the equator with data from July 1984. Such an archive is ideally suited to the development of long-term fire frequency models for the region, and can contribute to the sustainable management of ecosystems as well as for global carbon management.

** See <http://ptah.gvm.sai.jrc.it/wfw/> or <http://www.arc-iscw.agric.za/main/fireweb/index.htm>



occur only rarely, have low intensity and relatively insignificant impacts. In zones 3 and 5, widespread pastoralism means that fires are generally not desired because they result in a loss of forage. Fires are suppressed by farmers' associations in zone 3 whenever possible, and occasionally by local communities supported by the Ministry of Agriculture in zone 5.

In the Etosha National Park (zone 4), fire is managed by the Directorate of Resource Management (DRM) of the Ministry of Environment and Tourism (MET), using a park block burning pro-

gramme intended to maintain or improve biodiversity (Stander et al., 1993; Du Plessis, 1998).

In areas of Kavango and Caprivi in the east of zone 6, very frequent fires pose a serious threat to large areas of wooded and forested land (Mendelsohn & Roberts, 1997). In East Caprivi, communities were mobilised by the Directorate of Forestry (MET), with support from FINNIDA, to clear fire lines to retard fire spread and frequency in wooded and forested areas. In some areas, fire plays a more positive role, for instance in the regeneration of grasses used for thatching. Guidelines on burning have been prepared that recognise the need burn in some areas and to exclude fire in others (Trollope & Trollope, 1999).

8.6.2.3 Fire Information and Management

Fire statistics are not yet compiled or aggregated at a national level, and resources for obtaining them in the field are limited. The most comprehensive surveys of active fires and areas burned have been made using image data from the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard the US NOAA (National Oceanic and Atmospheric Administration) satellite series, as indicated in Cracknell (1997). The AVHRR data are provided by a PC-based receiver, installed at the Etosha Ecological Institute (EEI- within zone 4) and run by Park management.

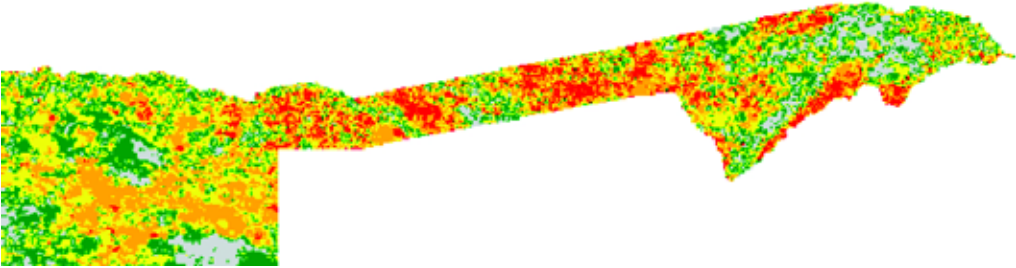
8.6.2.4 Remotely Sensed Products and Their Uses

Policy level

AVHRR-based maps showing the distribution and approximate timing of burned areas over the fire-

Figure 8.12. Fires in northern Namibia, for the 1997 burning season, colour coded according to approximate date of burn.
Figure 8.13. Six major fire regime zones of Namibia.

8.14



prone areas of Namibia (e.g. Figure 8.12) have been incorporated into environmental profiles of the Caprivi and North Central regions. These documents are designed to place environmental information into the hands of politicians and other decision-makers (Mendelsohn & Roberts, 1997; Mendelsohn et al., 2000). AVHRR-based maps have also been included in the latest fire policy document for Namibia (Goldammer, 1999), to show the distribution of burning. AVHRR data were also integrated with maps of vegetation and land use to stratify Namibia into different fire regime zones.

Fire frequency was then estimated from AVHRR imagery for the three most fire-prone fire regime zones (Trigg, 1997; Le Roux, 2001). Figures 8.14 and 8.15 show that fire frequency is much higher in zone 6 (Kavango and Caprivi) than elsewhere in the country, with the majority of Caprivi burning two to four times in just a four-year period (compare Figure 8.15[a] and Figure 8.15 [b]). Extensive areas of wooded and forested land in the Caprivi and Kavango are particularly under threat from such frequent fires (Jurvélius, pers.com., 1998). These remote studies help to identify areas where fire frequency is too high for

the intended land use, and for refining fire policy and management strategies.

Management level

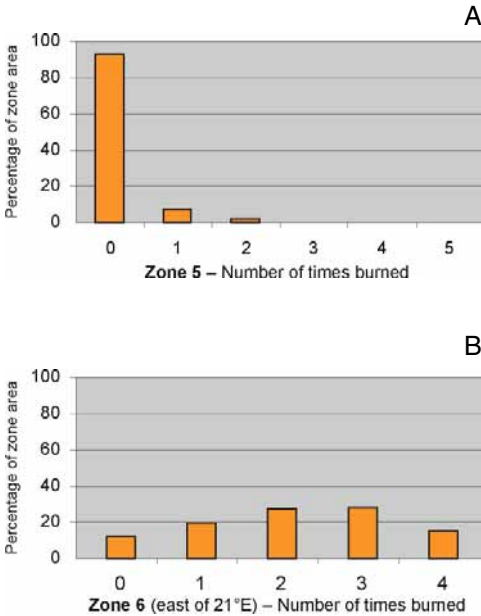
- Etosha Ecological Institute (EEI)

Active fires are usually visually interpreted from AVHRR channel 3 imagery within minutes of the satellite passing overhead, and their centre coordinates noted. This method has identified several undesired fires prior to their detection by management staff in the field, for more timely response.

Implementation of a block-burning programme requires mapping of all areas that burn within the park each year. During the 16 years of prescribed burning prior to the routine availability of AVHRR-based burned area products, this was done by either driving block perimeters or by sketching extents onto a base map from airborne observations. These methods were regarded as reasonably accurate for large, cleanly burned blocks, but inaccurate for heterogeneously burned blocks containing large islands of unburned vegetation. These methods of mapping burned areas also required a lot of time and resources. Since 1996, AVHRR data have enabled burned areas to

Figure 8.14. The number of times the areas of zone 6 (routinely monitored by AVHRR) burned over a four-year period (1996–1999).

8.15



be mapped, in many cases more accurately and with significantly less expenditure compared to field-based methods. Using a simple change detection technique, it now takes about two hours per month to map burned areas over the park and adjacent areas.

To plan new ignitions requires standing biomass to be estimated for each burn block, information that is very difficult to obtain for large areas using field-based methods alone. An AVHRR-derived image of the maximum NDVI attained at each pixel location during the previous growing season is used to identify candidate blocks with sufficient biomass for burning during the next dry season. The biomass of one or more candidate block is then surveyed using a disc pasture meter to assist the final selection.

• Caprivi

As part of their evaluation of the success of the community-based fire control project, the Directorate of Forestry (DoF) wanted to assess the impact of fire lines (cut by local communities) in reducing the annual area of burn in East Caprivi. An AVHRR-based study was commissioned and found that less of the area had burned in the years since the onset of fire-line construction, supporting the assertion that the fire control efforts had been worthwhile (Trigg, 1997). Burned area maps were also used in public awareness campaigns designed to educate people about the detrimental effects of very frequent fire.

8.6.2.5 Research and Development

Research at EEI and in Caprivi (Trigg & Flasse, 2000; 2001), helped to quantify and improve the accuracy of the remote sensing of burned areas in Namibia. These studies used field and Landsat TM-based surveys to assemble accurate reference data on burned areas. The various reference data were then used to assess the accuracy of existing burned area products from AVHRR and to develop new algorithms to detect burned areas using data from other sensors such as SPOT VEGETATION and MODIS (launched December 1999).

8.6.3 Botswana

Botswana's terrain consists almost entirely of a broad, flat, arid subtropical plateau, though there are hills in the eastern part of the country. In the north-west, the Okavango River runs into the sands of the Kalahari. The Chobe National Park is a beautiful grassland reserve, popular for its large elephant

Figure 8.15. Percentage of land that has burned a different numbers of times within a set number of years: (a) shows the percentage of zone 5 that burned between 0 and five times during a five-year period (1994–1998); (b) shows the percentage of zone 6 (east of 21°E) that burned between 0 and four times during a four-year period (1996–1999).

population. The Kalahari Desert, a varied environment of sand, savanna and grassland, covers large parts of the country. This is an important wildlife area, in which Botswana's two largest conservation areas, the Central Kalahari Game Reserve and the Kgalagadi Transfrontier Park (including the Gemsbok National Park in Botswana and the Kalahari Gemsbok National Park in South Africa), are located. The country has a sub-tropical climate arid in the south-west. Maximum daily temperatures vary from 23–32° C. During the winter months, May to September, there are occasional overnight frosts. The majority of the rain falls in the north and the east, almost all in summer between October and April.

8.6.3.1 The Fire Issues in Botswana

Fire is a natural occurrence in Botswana. The vegetation types and ecosystems across most of the country have evolved with fire as a major shaping force.

With the correct frequency, timing and extent of burning, fires can have many positive effects including maximising range productivity, promoting species diversity and controlling bush encroachment. Many rangeland vegetation types actually require a combination of fires, grazing or browsing to maintain the species diversity and productivity.

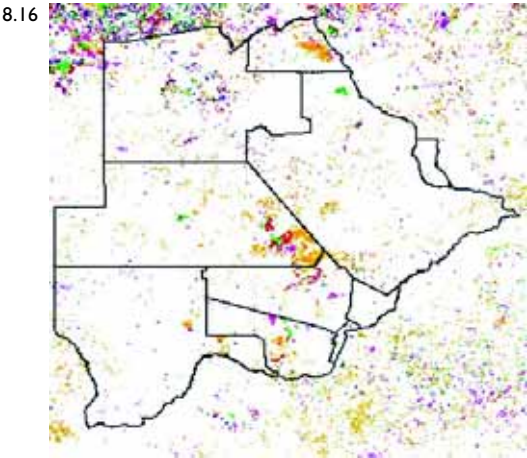
However, too often, fire seems to be used inappropriately, or to get out of control, resulting in undesired effects. Fire monitoring has shown that large areas of Botswana burn every year with an average of 8–15% (48–90 000 km²) of the country affected each year. These large and frequent wildfires cause damage to property and

threaten lives, damage forest, reduce grazing availability, change vegetation ecology, increase the impact of drought, increase soil erosion and land degradation and cause increased wildlife and livestock mortality.

The management and control of bush fires in Botswana is a critical issue for the sustainable development of the livestock, forestry and wildlife sectors. Fire is already extensively used as a range management tool throughout the southern African region for maximising rangeland productivity. The Ministry of Agriculture and other government departments have recently put fire management on their agenda as a priority and are developing policies to improve knowledge on the potential problem and strategies to tackle the issues. It is recognised that many issues need to be addressed, such as improving knowledge on fire and wildland ecology, knowledge on the socio-economic causes and consequences of fires, and community education on fire management.

8.6.3.2 Fire Information and Management

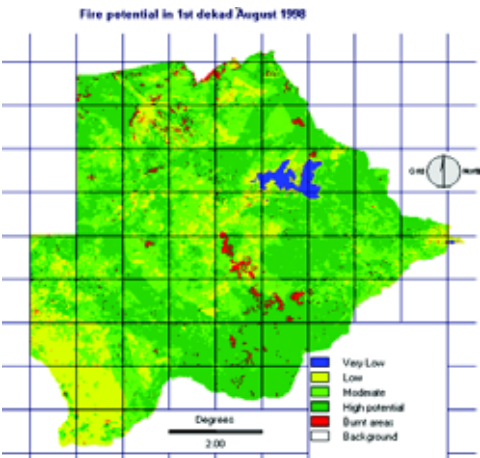
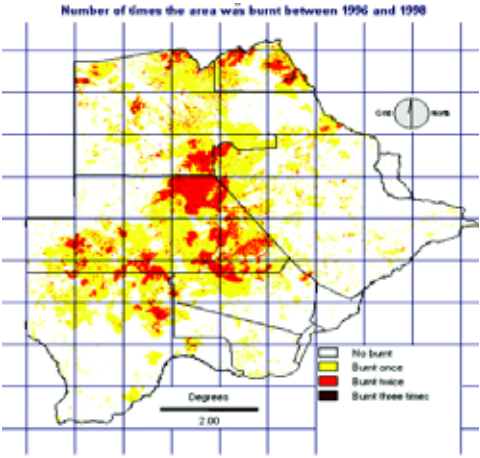
In Botswana, the Agricultural Resources Board (part of the Ministry of Agriculture) has overall responsibility for fire management. Information is typically required at two levels: (a) on an operational basis (mostly active fires and vegetation status) to react to actual conditions and act appropriately, and (b) to document the situation. The latter is used to improve knowledge of the potential problem, to assist strategic decision-making, and eventually to assist in evaluating the effectiveness of actions. Good archives are essential to monitor trends and evolution of fires and burned areas. While there are mechanisms for



fire reporting in Botswana, the documentation of fire events is incomplete. For example, when vehicles are available, the extent of burned areas is estimated by driving around them. This operation is time consuming and can be highly inaccurate due to the heterogeneity of the burned areas.

Countries as large as Botswana, that contain extensive areas of fire-prone rangeland, could not justify the expenditure needed to install and maintain observational networks for collecting fire information regularly at a national level (over the entire territory). This is where remote sensing data such as NOAA-AVHRR can be used as a substitute to fill in gaps where data is not available, or at least to prioritise action where resources are limited.

While the Government of Botswana intends to improve strategies on fire management nationally, current resources are limited. When undesired active fires are discovered in the field in time, village resources are combined with any



available district resources to combat the fire. However, most effort is put into prevention, such as the establishment and maintenance of firebreaks. There are currently 6000 km of firebreaks in Botswana, which require regular maintenance to be effective, and there are plans to bring the extent of the network up to 10 000 km.

Figure 8.16. AVHRR-based burned area map (June–October 1998). Each colour corresponds to the date at which the area burned.

Figure 8.17. AVHRR-based fire frequency map for Botswana 1996–1998 (Ntabeni, 1999).

Figure 8.18. AVHRR-based prototype fire danger map for Botswana (Ntabeni, 1999).

8.6.3.3 NOAA-AVHRR Products and their uses

The Government of Botswana, through the Department of Meteorological Services (DMS), requested the UK Department for International Development's assistance in developing the capacity to access and utilise data from satellite remote sensing in order to complement the monitoring of weather, climate, vegetation and fires. With a PC-based NOAA receiver maintained and run by local staff, DMS has been monitoring vegetation status and burned areas since 1996, working closely with the Botswana Rangeland Inventory Monitoring Project. They then feed the information to decision makers in the Agricultural Resources Board and Inter Ministerial Drought Committee. While the data is potentially very useful, it takes time and iterations of the products that are delivered for product users to appreciate the potential and product developers to meet decision makers' requirements.

Vegetation status maps, as designed by Sannier et al. (1998), have been used operationally by the drought committee for the early identification of problem areas. The usefulness of fire information from NOAA-AVHRR was not directly perceived. Initial burned area maps attracted attention of decision-makers. Obtained by visual analysis and digitisation on the screen, their production was time consuming and the results missed most small burned areas. Demand arose for an operational approach to automatically detect burned areas from the AVHRR data acquired daily. Current knowledge in burned area detection was applied to create an operational prototype to produce maps automatically (Flasse, 1999). While providing very

sensible results (Figure 8.16), additional issues rose, underlying the complexity of automated burned area detection from AVHRR data.

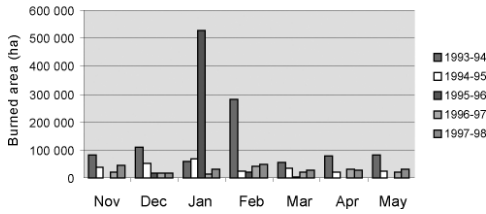
As complete daily coverage of Botswana is available, burned area products can be produced, using the region and frequency that best suit users' requirements. For example, daily data are sometimes used to monitor evolution of large fires lasting several days, while monthly syntheses are used by the Central Statistics Department of the Ministry of Finance. Perhaps of greater importance is the accumulation of data on burned areas over a number of years, particularly for monitoring the frequency of fire occurrence (Figure 8.17). This is of value to rangeland management because of the strong link between the frequency and impact of fire. It is also an important indicator to contribute to risk assessment of fire occurrence. In addition, firebreaks will be maintained with priority in areas where fuel load is not reduced by fires in the past years.

While the burned area product from AVHRR data, even though not perfect, is slowly entering into the routine of fire management, the Agricultural Resources Board is increasingly interested in the AVHRR data potential. For the 2000 fire season, they requested and received information from DMS on detected active fires, in near-real-time.

Finally, local staff is currently working on a first prototype method to produce ten-day fire potential maps for Botswana (Ntabeni, 1999), an example of which is given in Figure 8.18. The model uses various inputs, such as AVHRR NDVI, from the wet season as an indicator of fuel load, AVHRR RGI (Relative Greenness Index) during

8.19

Monthly burned area for Senegal from 1993 to 1998



8.20



the dry season as an indicator of vegetation status, AVHRR burned area maps, roads and settlements, land use and vegetation maps.

The fire products obtained from NOAA-AVHRR provide a very valuable contribution to improved knowledge and fire management decision-making. Some of the existing products are already used operationally. The more decision makers see and use these products, the more they learn about their potential and gain useful insights as to how it would best support them.

8.6.4 Senegal

8.6.4.1 The Fire Issues in Senegal

The fire season extends from October to May. Overall, the critical fire period in Senegal is variable between seasons. It depends on several factors, including the rainfall (quantity and length), the fuel production, vegetation status, spatial distribution, awareness of population and prescribed burning practices (CSE, 1999). Particularly in the Sahelian part of Senegal, fire occurrence contributes to increasing pressure on agricultural and rangeland systems through the destruction of natural pasture equilibrium and the weakening of

agricultural land. The fire activity on the forests of the southern part of the country results in a decrease in the wood productivity as well as a threat on regeneration. Bush fire is one of the main causes for the degradation of natural resources, and often results in changes in vegetation as well as the living conditions of the local populations.

These fires are generally characterised by their frequency, their unpredictability, and their variable intensity. These are linked in turn to the state of the vegetation or fuel, the variety of existing ways to exploit natural resources and to the social conditions of local communities (Mbow, 1997; CSE, 1999).

The Government of Senegal put means in place to fight the bush fires in the principal eco-geographic zones of the country. Where organised, communities are provided with equipment to fight the fires (*active activities*). *Passive activities* consist more of awareness campaigns to help local communities avoid conditions favourable to wild fires. In the Sahelian part of the country a network of firebreaks was established in order to reduce fire spread or even stop it in areas where

Figure 8.19. Monthly burned area for Senegal between 1993 and 1998 (source: CSE).

Figure 8.20. Fire frequency in Senegal between 1996 and 1998 (source: CSE).

natural obstacles are rare. However, firebreaks tend not to be maintained because of the cost associated with the operations and their efficiency is therefore reduced. One of the most important strategies was introduced in 1965, consisting of early season prescribed fires to reduce fuel load and therefore to prevent late fires (much larger, more difficult to control and more destructive). When applied appropriately, this method is very efficient. The effectiveness of those strategies goes together with an appropriate use of fire information by the public services as well as the general public. Traditionally, fire information consisted of field reports of observed or fought fires. However, the delay in providing active fire information is usually proportional to the distance between the fire and the fire-fighting unit. In addition, the spatial and temporal variability of the bush fire activity often exceeds the current means to react.

8.6.4.2 Fire Monitoring

The estimation of burned areas and the fire frequency are fundamental aspects to try to manage the natural resources with respect to fire activity. To complement traditional fire information and government initiatives, the Centre de Suivi Écologique (CSE) of Dakar has implemented a methodology to monitor fire activity using NOAA-AVHRR satellite data received locally through their own station installed in 1992. Fires are identified using night-time imagery and simple threshold techniques. In 1999 the CSE became one of the nodes of the World Fire Web of the Joint Research Centre (EU), which provides operationally active fire information during daytime. The fire information is introduced, via GIS, into its geographical

context, allowing improved interpretation and therefore support to management.

While not exhaustive, it is now well accepted that fire information obtained from AVHRR data provides good indication of the fire activity over large territory. Initially only the territory of Senegal was covered, and information operationally used by the Forestry, Waters, Hunting and Conservation Department, the Livestock Directorate and the National Parks Directorate. Now CSE monitoring activities are also contributing to providing fire information for the neighbouring countries.

8.6.4.3 Fire Activity During 1993–1998

The analysis of the fire information over the period 1993 to 1998 resulted in a description of the fire activity in Senegal and the identification of important issues.

The problematic period is often January to February, when remaining high volume of vegetation is senescent and the weather very dry. During that period large uncontrolled wild fires can be very destructive. The spatial and temporal distribution is generally heterogeneous and variable.

Figure 8.19 illustrates this variability and clearly indicates peak fire activity in February 1994 and January 1996. In 1994, these can probably be explained by the absence of prescribed fires. In 1995/6, high rainfall continued until November, increasing fuel loads and delaying the application of prescribed fires. This is believed to be the main cause of the recrudescence of fires of January 1996.

The *regression* period is characterised by a sharp decrease in area burned due to a corresponding decrease in fuel load (vegetation already burned

or grazed). It takes place between March and May. However, during that period, the data quality is affected by increased cloud cover over the south of the country. It is also in this area that the late season fires are observed. Slash and burn agriculture is practised in the south-east, which usually sees an increase in fire activity at the end of the dry season, corresponding to field preparation for the coming crop season.

Spatially, as is illustrated in Figure 8.20, fire activity occurs in the centre, south and south-west. Most of the fire activity takes place in the regions of Kolda, Tamba and Ziguinchor, because of their continuous herbaceous cover combined with human activities such as honey and gum collection, hunting and charcoal production. In the north of the country, the lower biomass is usually used by the cattle and fire activity is consequently very low.

8.6.4.4 Partners

The Forestry, Waters, Hunting and Conservation Department (DEFCCS) is responsible for fire control activities. It puts into place the policy of fire prevention and fire fighting, but it lacks means. CSE provides the DEFCCS with fire information that is used to identify the locations and size of fires. This information helps managers to focus on fragile areas as well as to allocate resources appropriately.

The Livestock Directorate is responsible for the management of rangeland, indispensable to feed the cattle. Since bush fires destroy valuable forage, often resulting in over-grazing, fire information provided by the CSE is used to better organise pastoral movements. However, with the recent decentralisation processes, fire control

responsibilities and pastoral movements have been transferred to local communities. Unfortunately, the newness of the process combined with scarce resources prevents local communities from playing their role suitably.

The National Parks Directorate receives from CSE, in near-real time, information on the fire activity in the *Parc National de Niokolo Koba*, important heritage for its flora and fauna. Fire information is used by the managers of the park to assess awareness campaigns in the neighbouring villages, as well as to prescribe burning activities.

Finally, through international collaborations, the impact of radio campaigns in Guinea has been assessed using remote sensing fire information from CSE. The study showed a reduction of fire activity in areas covered by the radio campaigns (Kane, 1997). Clearly the fire issues are interdisciplinary and must be tackled as a common and integrated effort where satellite data can positively contribute to efficient fire management.

8.6.5 Ethiopia

In February to March 2000, Ethiopia experienced damaging large forest fire events impacting on the only remaining significant natural forest areas of the Eastern Highlands. These areas are an important part of the Protected Areas System of Ethiopia, for their biodiversity as well as resources for the local communities. In Bale alone, these fires affected 45 forest priority areas, damaged 53 000 ha of forest and 1000 ha of wild coffee, killed 30 head of livestock and 49 of wildlife, destroyed over 5000 beehives and 43 houses. Whether for the short term or the longer term, these fire events clearly affected resources

important to people's livelihoods. However, the wider issues linked to fire are complex, and people are usually at their origin. Mainly pastoralists, farmers, hunters and honey gatherers are starting the fires in Ethiopia. There is an increased demand for farmland to sustain the livelihood of the fast growing population. Given the backward agricultural techniques with low productivity, expansion of farmland is the only option for many families. In addition, activities by immigrants with no cultural affiliation with the forests, and therefore little knowledge on the ecology of forest, represent an important threat to the sustainability of their main natural resources. Through the Global Fire Monitoring Center, the Government of Ethiopia received emergency support from the international community (Germany, USA, South Africa, Canada, UNEP). In particular, the United States National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite, Data, and Information Service (NESDIS), International and Interagency Affairs Office, on the request of the Government of Ethiopia through its embassy in Addis Ababa, provided the following remote sensing fire information:

- Images from the DMSP (US Air Force Defence Meteorological Satellite Program) images at 2.7 km resolution for the East Africa region. A special survey area where the fires occurred (Goba and Shakiso Regions: 5–9°N, 38–42°E), were produced daily (weekdays).
- Images from the NOAA-AVHRR (Advanced Very High Resolution Radiometer) at 1 km resolution (recorded onto NOAA-14 spacecraft), from 8 to 10 March 2000 and occasion-

ally later. Restrictions were due to the fact that the satellite's orbital track changed and the spacecraft did not image directly over Ethiopia due to other commitments for recording 1 x 1 km resolution data.

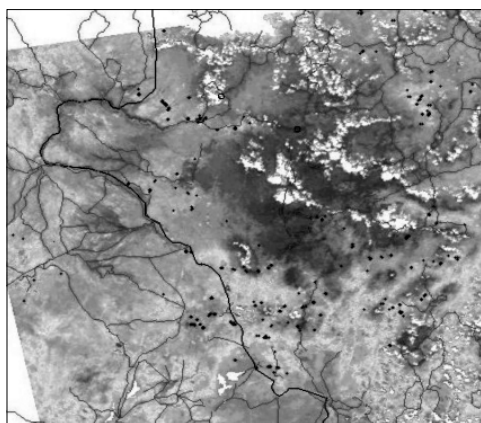
Fire maps were particularly useful during the emergency period to assess the evolution of the situation and help flying crews identifying active fire locations.

8.6.5.1 Fire Information and Management

The Government of Ethiopia recently decided to start the development of integrated fire management strategies in order to prepare for catastrophes, and most importantly to prevent them through improved awareness and integrated fire management in order to benefit in the long term both the local communities and the forest ecosystem. The first step was a Round Table Conference on forest fire management in September 2000, in order to learn from the past events and from experiences in other countries and so define recommendations for the coming years (Ministry of Agriculture, Ethiopia, with GTZ and GFMC 2001).

The Round Table clearly recognised the importance of taking into account all aspects relating to the fires, with particular attention given to the status of the people initiating them. The development of a fire information system and the use of fire remote sensing capabilities were recommended, and particular emphasis was placed on the existing remote sensing capabilities of the Ethiopian National Meteorological Services Agency (NMSA), in Addis Ababa (Flasse, 2000).

8.21



8.6.5.2 NOAA-AVHRR Products and their uses

The NMSA hosts receiving stations for the NOAA-AVHRR and Meteosat satellites. Initially implemented in 1990 in support of drought preparedness (Tsegaye et al., 1995), the same data can be interpreted for fire management. NMSA already operates the systems and collect satellite data daily. In December 2000 – further to the Round Table recommendations – those capabilities were upgraded to cover fire information. Both NMSA and Ministry of Agriculture staff were trained to use active fire detection software, to extract active fire locations and to integrate the information into the forestry GIS.

The forest and fire community in Ethiopia is now starting to build on this new expertise to benefit from timely and national fire information from satellite data. An example is given in Figure 8.21.

8.7 FUTURE EXPECTATIONS

The NOAA-AVHRR, Landsat and SPOT satellite systems have been the workhorses for land cover applications until recently. Several new remote sensors have been developed for the “new generation” of satellites reflecting the trend in remote sensing towards increasingly specific applications and higher sensor resolution. This leads to a tremendous increase in the amount of data in need of processing and storage, but concurrent advances in computer hardware and software are keeping pace with requirements. There is greater emphasis on making remote sensing products more accessible to a wider range of users. This means that, not only will raw imagery be available, but also derived information products that are more user-friendly, for those without a remote sensing background. Some of these new data products include maps of net primary production, leaf area index, land cover change, and fire. Furthermore, new data and data products are increasingly available for free (e.g. EOS data) or at substantially lower cost than ever before (in the case of Landsat 7).

The first and second Along Track Scanning Radiometer (ATSR) instruments, ATSR-1 and ATSR-2, have been operating since 1991 and 1995 on board the ERS-1 and ERS-2 satellites, respectively. The Advanced ATSR (AATSR) instrument will be launched on ESA's Envisat platform in the near future. ATSR-2 and AATSR have green, red and NIR channels for vegetation monitoring, in addition to the two SWIR and two TIR channels on ATSR-1. Swath width is 500 km and spatial resolution at nadir is 1 km. The key feature of ATSR is that it can deliver both nadir and “along

Figure 8.21. Vegetation (NDVI) and active fire information from NOAA-AVHRR data over west Ethiopia.

track" views of the same surface location where the latter view passes through a longer atmospheric path, thus enabling improved corrections for atmospheric effects.

The Meteosat Second Generation (MSG) programme will continue where the Meteosat programme began in 1977, and will be particularly useful for regional/continental-scale monitoring of fires, much like the AVHRR. In addition, it will provide data every 15 minutes, allowing the monitoring of fire progression and fire temporal distribution. The MSG satellites will operate from geostationary orbits, and provide multi-spectral imagery in 12 spectral channels, at 1 km spatial resolution in the visible channel and 3 km for the others, 8 of which will be in the TIR. Most National Meteorological Services in Africa are expected to be equipped with the relevant receivers, allowing near-real time monitoring in-country.

The two principal EOS (Earth Observing System – NASA) platforms are Terra (EOS AM-1) and Aqua (EOS PM-1). Both Terra and Aqua feature the Moderate Resolution Imaging Spectrometer (MODIS). The MODIS instrument on board Terra is considered more useful for land surface applications due to its morning flyover time, especially in the tropics, where clouds usually develop by afternoon. MODIS has a swath width of 2330 km and a repeat cycle of one to two days, which makes it the principal sensor for monitoring the Earth system, replacing AVHRR, but with some important improvements. The red and NIR bands have a spatial resolution of 250 m, allowing global NDVI information at much finer resolution than with AVHRR. Bands 3–7 (500 m) and 8–36 (1000 m) provide additional data in the

short-wave infrared (SWIR) and thermal infrared (TIR) wavelengths. MODIS data is contributing substantially to global fire monitoring, along with fire effects on land and atmospheric processes. Furthermore, a range of MODIS active fire products are already freely available online (Annexure 1), and a 500m burned area product is being refined and evaluated ready for general release.

A new type of sensor on board Terra is ASTER, which consists of three separate subsystems corresponding to three spectral regions: Visible and Near Infrared (VNIR), Shortwave Infrared (SWIR) and Thermal Infrared (TIR). The VNIR subsystem has three spectral bands in the visible and NIR wavelengths, with 15 m spatial resolution. The nadir-looking detector is complemented by a backward-looking detector to permit stereo viewing in the NIR band. The SWIR subsystem features six spectral bands in the near-IR region, with 30 m resolution. The TIR subsystem has five bands in the thermal infrared region, with 90 m resolution. ASTER's 60 km swath width gives it some continuity with SPOT, and ASTER images are already proving useful for detecting burned areas and capturing real-time fires.

Another new sensor on Terra, the Multi-angle Imaging SpectroRadiometer (MISR), features nine widely spaced view angles for monitoring the Earth's surface. This capability allows for the improved extraction of quantitative parameters describing the surface of the Earth through, for example, the inversion of bi-directional reflectance models. MISR provides coverage of the entire Earth's surface in swaths 360 km wide by 20 000 km long, every nine days. Pixel size is

250 m at nadir, and 275 m from the off-nadir cameras.

An important consideration for monitoring land cover change over dekadal (ten-day) time scales is data continuity between satellites and satellite systems. The Landsat satellite series began in 1972, and thus represents the longest available time series. The most recent addition to the Landsat programme was Landsat 7, which began providing data in July 1999. Landsat 7 has an Enhanced Thematic Mapper (ETM+) instrument that features enhanced radiometric resolution in the six TM channels, plus improved spatial resolution in the thermal channel (60 m), plus a panchromatic band with 15 m spatial resolution. Similarly, SPOT imagery has been available since 1986, and the SPOT series was enhanced with the launch of SPOT 5 in 2002. AVHRR also provides nearly 20 years' daily data over the whole globe. Since 1998, the coarse-resolution SPOT-VEGETATION sensor has provided another tool comparable to AVHRR for daily monitoring of global vegetation at 1 km spatial resolution, in four spectral bands (blue, red, NIR and SWIR).

In conclusion, the future is now with regard to remote sensing of fires and fire effects on land cover and landscape processes. Recent, dramatic improvements in remote sensing and data processing capabilities, data product availability and internet access should lead to equally dramatic improvements in remote detection, measurement and monitoring of fires and fire effects.

8.8 ANNEXURE 1

INTRODUCTORY TEXTBOOKS

Wilkie, D.S. and J.T. Finn. 1996. *Remote Sensing Imagery for Natural Resources Monitoring – A Guide for First-Time Users*. Columbia University Press, New York.

Sabins, F.F., Jr. 1996. *Remote Sensing: Principles and Interpretation*. 3rd ed. Freeman, New York.

Lillesand, T.M. and R.W. Kiefer. 1999. *Remote Sensing and Image Interpretation*. 4th ed. John Wiley, New York.

Barrett, E.C. and L.F. Curtis. 1999. *Introduction to Environmental Remote Sensing*. 4th ed. Nelson Thornes, London.

Campbell, J.B. 1996. *Introduction to Remote Sensing*. 2nd ed. Taylor & Francis, London.

Gibson, P. and C. Power. 2000. *Introductory Remote Sensing Principles and Concepts*. Routledge, London.

STATE-OF-THE-ART REVIEW

Ahern, F., J.G. Goldammer and C. Justice (eds.). 2001. *Global and regional vegetation fire monitoring from space: Planning a coordinated international effort*. SPB Academic Publishing bv, The Hague.

Innovative Concepts and Methods in Fire Danger Estimation (Proceedings of the 4th International Workshop on Remote Sensing and GIS Applications to Forest Fire Management, Ghent, Belgium, 5-7 June 2003). <http://www.geogra.uah.es/earsel/report1.html>

USEFUL WEB PAGES ON REMOTE SENSING

The following are good places to start from as they contain lots of links to other remote sensing pages:

The Remote Sensing and Photogrammetry Society:
<http://www.rspoc.org/>

WWW Virtual Library: Remote Sensing
<http://www.vtt.fi/tte/research/tte1/tte14/virtual/>

Universiteit Utrecht
<http://www.frw.ruu.nl/nicegeo.html#gis>

ACRONYMS, ABBREVIATIONS AND EXPLANATIONS

AATSR	Advanced Along-Track Scanning Radiometer (visible/infrared sensor on Envisat series, successor of ATSR)
AMI	Active Microwave Instrument (SAR sensor on ERS series)
Aqua	EOS satellite (formerly known as EOS PM-1)
ARVI	Atmospherically Resistant Vegetation Index
ASAR	Advanced Synthetic Aperture Radar (microwave sensor on Envisat; successor of AMI)
ASTER	Advanced Spaceborne Thermal Emission & Reflectance Radiometer (sensor on Terra satellite) website: http://asterweb.jpl.nasa.gov/
ATSR	Along-Track Scanning Radiometer (visible/infrared sensor on ERS series) website: http://earthnet.esrin.esa.it
AVHRR	Advanced Very High Resolution Radiometer (sensor on NOAA satellite series)
DAAC	Distributed Active Archive Center (US data collection points, these can usually be easily accessed via the Internet)
DMSP	Defense Meteorological Satellite Program (USA)
EDC	EROS Data Center (part of United States Geological Survey), data sales (hosts a DAAC)
Envisat	Satellite, successor to ERS programme
EOS	Earth Observing System (NASA's Earth Science satellite programme)
EOSDIS	Earth Observing System Data and Information System. The EOS Data Gateway provides a central search and order tool for accessing a wide variety of global Earth science data and information held at 8 different EOSDIS data centres and a growing number of international data providers.
ERS	European Remote Sensing Satellite series
ETM+	Enhanced Thematic Mapper (sensor on Landsat-7) website: http://landsat7.usgs.gov/
Geostationary	A type of satellite orbit (at 36 000 km above the equator) where the motion of the satellite matches the speed and direction of the Earth's rotation so that the satellite remains over a fixed point on the Earth's surface. Also called geosynchronous.
GEMI	Global Environment Monitoring Index
GES	GSFC (Goddard Space Flight Center) Earth Sciences (hosts a DAAC with MODIS data)
GFMC	Global Fire Monitoring Center website: http://www.fire.uni-freiburg.de/
GOES	Geostationary Operational Environmental Satellite – meteorological satellite programme (USA)
HRV	High Resolution Visible (sensor on SPOT-1, -2 and -3)
HRVIR	High Resolution Visible Infrared (sensor on SPOT-4 and -5)
Ikonos	Space Imaging EOSAT high resolution visible satellite series
IRS	Indian Remote Sensing Satellite series
JERS	Japanese Earth Resources Satellite (visible/near infrared and microwave sensors)
Landsat	Land use studies satellite series (USA) (variously carries sensors MSS, TM and ETM+)
LARST	Local Applications of Remote Sensing Techniques (former programme of Natural Resources Institute)
LMIR	Long Mid-Infrared (waveband or sensor channel)
Meteosat	European meteorological satellite series
MIR	Mid-Infrared (waveband or sensor channel)
MISR	Multi-angle Imaging Spectro-Radiometer (sensor on Terra satellite) website: http://www-misr.jpl.nasa.gov/
MODIS	Moderate Resolution Imaging Spectrometer (sensor on Terra satellite) website (info): http://modis.gsfc.nasa.gov/ and http://edcdaac.usgs.gov/main.html

MSG	Meteosat Second Generation (satellite series, successor to Meteosat) website: http://www.esa.int/msg/	SAFNet	Southern African Fire Network website: www.safnet.net
MSS	Multispectral Scanner System (sensor on Landsat series)	SAR	Synthetic Aperture Radar (microwave sensor)
NASA	National Aeronautics and Space Administration (USA)	SAVI	Soil Adjusted Vegetation Index
NDVI	Normalized Difference Vegetation Index	SMIR	Short Mid-Infrared (waveband or sensor channel)
NIR	Near Infrared (waveband or sensor channel)	SPOT	Satellite Pour l'Observation de la Terre (SPOTImage (French) satellite series) website: http://www.spot.com
NOAA	National Oceanic and Atmospheric Administration (USA, also the name of their satellite series)	SSM/I	Special Sensor Microwave Imager (passive microwave sensor on DMSP)
OrbView	OrbImage high resolution visible satellite series	Terra	EOS satellite (formerly known as EOS AM-1)
PAN	Panchromatic (often used to refer to sensor data with a single waveband visible channel, e.g. SPOT PAN)	TIR	Thermal Infrared (waveband or sensor channel)
Polar orbit	An orbit where the satellite flies around the Earth travelling approximately north to south (or south to north) so that its path goes over the polar regions.	TM	Thematic Mapper (sensor on Landsat-4 and -5)
Radarsat	Canadian radar satellite (with SAR sensor)	TSAVI	Transformed Soil Adjusted Vegetation Index
SAC	Satellite Applications Centre (South Africa, data sales)	USGS	United States Geological Survey (includes EROS Data Center, data sales)
		VGT	Vegetation (AVHRR-like sensor on SPOT-4 and -5)
		VIS	Visible (waveband or sensor channel)
		XS	Often used to refer to SPOT multispectral data

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(see overleaf)

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Table 8.1. Some satellite sensors and data providers

Satellite sensor	Spatial resolution	Temporal resolution	Spectral bands	Cost indication per scene (approx.)
<i>Geostationary satellites – for example for Africa:</i>				
Meteosat	2.4-5km	30 min	Visible, infrared, water vapour	Free with receiving equipment and license (variable cost, free to some users) from Eumetsat
MSG	1-3km	15 min	12 bands	
<i>Polar orbiting satellites (low / medium resolution) – for example:</i>				
NOAA-AVHRR	1100m	< 1 day	5 bands: red, NIR, MIR, 2xTIR	Free with receiving equipment or basically cost price if ordered
SPOT-VEGETATION	1150m	1 day	4 bands: blue, red, NIR & SMIR	Contact SPOT image Free
Terra MODIS	250m 500m 1000m	1-2 days	36 bands [visible to infrared]	Free
<i>Polar orbiting satellites (high resolution) – for example:</i>				
SPOT	10m 20m 3m	26 days or less	green, red, NIR & SMIR Panchromatic / visible	Spotimage prices: • 1250 – • 5100
Landsat TM	30m 120m / 60m 15m	16 days	7 bands: blue, green, red, NIR, SMIR, LMIR & TIR Panchromatic: 1 band: visible/ NIR	Landsat 5 TM: \$ 2870 Landsat 7 TM: \$ 600
ERS SAR	12.5-30m	26 days	Radar	Eurimage: \$ 1200 (discounts for multiple images)
ERS SAR	12.5-30m	26 days	Radar green, red,	Eurimage: \$ 1200 (discounts for multiple images)
IRS	23m 5.8m	24 days	NIR, SWIR Panchromatic/ visible	Spaceimaging Europe: • 2500
Ikonos	4 m 1m		blue, green, red, VNIR Panchromatic: visible	Expensive (varies with product and quantity of data)
<i>Other useful sites</i>				
Vegetation (NDVI) and Rainfall (CCD)				Free
Fire products				Free

**Data Access /
Address****Contact / Internet
information**

Eumetsat	http://www.eumetsat.de/en/dps/helpdesk/ msg_suppliers.html
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Satellite Applications Centre (SAC) P.O Box 395 Pretoria 0001 Republic of South Africa GSFC DAAC Spot Image, France	Tel: +27 (12) 334 5000 Fax: +27 (12) 334 5001 CustomerSac@csir.co.za http://www.sac.co.za/ http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/ BRS_SRVR/avhrrbrs_main.html http://www.vgt.vito.be/ http://free.vgt.vito.be/
EOSDIS GES DAAC	http://redhook.gsfc.nasa.gov/~imswwww/pub/ imswelcome/plain.html http://daac.gsfc.nasa.gov/MODIS/ MODIS User Services: Phone: +1 (301) 614 5224 Fax: +1 (301) 614 5304 help@daac.gsfc.nasa.gov

SACSPOT image, France	(see above) http://www.spot.com
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SAC USGS (Landsat 7)	(see above) custserv@edcmail.cr.usgs.gov http://landsat7.usgs.gov/
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Eurimage SAC	(see above) http://earth.esa.int/helpandmail/ help_order.html
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Eurimage SAC	(see above) http://earth.esa.int/helpandmail/ help_order.html
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Spaceimageing EOSAT	csc@si-eu.com http://www.spaceimaging.com/ products/irs/irs_technical_overview.htm
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SAC Space Imaging EOSAT	(see above) http://www.spaceimaging.com/ default.htm
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ADDS African Data Dissemination Service	http://edcintl.cr.usgs.gov/adds
---	---

WFW World Fire Web Iona Fire See also GFMC-remote sensing MODIS: Daily images and active fires Internet fire mapping tool Daily active fire text files	http://www.gvm.jrc.it/TEM/wfw/wfw.htm http://shark1.esrin.esa.it/ionia/FIRE/ http://www.fire.uni-freiburg.de/inventory/ rem_pro.html http://rapidfire.sci.gsfc.nasa.gov http://maps.geog.umd.edu ftp://maps.geog.umd.edu
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9

FIRE PROTECTION PLANNING, REGIONAL INTEGRATION AND FIRE DANGER RATING

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9.1 FIRE PROTECTION PLANNING

9.1.1 Systematic Fire Protection

Many African countries have a serious fire problem. Increasing frequency and intensity of fires are having a negative effect on ecosystems and are leading to a general degradation of the land in many areas. The search for a solution is difficult. Systematic Fire Protection (SFP) offers a framework for developing a fire protection program designed to address this problem. SFP was developed in the USA in 1914 during a time when fires were destroying major areas of forested land, not unlike the situation in many African countries today. Throughout the world, countries, including Canada, Australia and the United States, use approaches similar to SFP.

A fire starts from an ignition source and spreads. As it spreads, it becomes larger in size and perimeter. The larger it becomes, the more

difficult it is to control, resulting in higher costs and greater damage to valuable resources. Actions are taken to stop the fire's spread and limit the time the fire burns unchecked. Eventually the fire is brought under control. Systematic Fire Protection's goal is to reduce the size of the fire through a series of actions that are aimed at reducing the cumulative time required to control the fire's spread. The framework of SFP consists of several integral steps that can be applied in a number of ways. These steps are:

9.1.1.1 Fire Prevention

Fire prevention's goal is to prevent a fire from occurring and consists of two activities. The first is to reduce the production of fire brands from various sources and the second is to reduce the susceptibility of vegetation to ignition by some form of treatment.

9.1.



TIME

= fire spread
= fire damage
= larger fires
= more firefighters
= more costs

- *Fire pre-suppression*
Actions taken in anticipation of a fire are referred to as pre-suppression. This can involve training and equipping resources, as well as modifying fuels or constructing fire belts.
- *Detection*
In order to take quick action on a fire, it must be detected as closely as possible to its time of ignition. Detection triggers all suppression actions and is critical in minimising fire size and costs. Methods of detection include look-out towers, aircraft, infra-red scanners, patrols and public reports.
- *Location*
Once a fire has been detected, it must be located on a map or with other means in order to provide accurate information to personnel responding.

- *Dispatch*
Once the location of the fire is determined, a decision must be made about strength of attack and specific forces to be sent.
- *Communication*
The location and fire information is then transmitted to the forces being dispatched. Methods used may range from radio to bicycle messenger.
- *Travel*
Once forces have received the dispatch order, they must travel to the fire using the fastest conveyance and routes possible.
- *Attack*
Stopping the fire's spread as quickly as possible, using the personnel and equipment available, is the goal of fire attack.
- *Mop-up*
Once the fire's spread has been halted, the next step is to secure the fire by extinguishing and cooling all hot spots.

The key objective of the above steps is the reduction of time a fire burns to keep it from spreading, thus reducing the damage and loss, and the cost of fire suppression. This is the primary aim of SFP.

Application of SFP involves the thoughtful analysis of the fire programme. Reductions in the overall time required to suppress fires usually require spending more money on equipment and personnel. This expenditure must be weighed against potential damage to resources and other values.

Figure 9.1. Time is the adversary (M.F. Calvin).

9.1.2 Determining Fire Protection Objectives

The first step in applying Systematic Fire Protection is to determine the fire protection objectives for all the areas within the organisation's jurisdiction. Not all land need be protected at the same level. For example, the fire protection level for a commercial pine plantation will be quite different from semi-desert shrub land. Determining objectives can be accomplished by subjective means, or it can be done in a more logical manner, as described below.

A logical and rational approach to establishing fire protection objectives begins by delineating areas of similar vegetation, topography, climate, protection constraints, etc. This allows fire protection to be targeted and prioritised. Area evaluation of values at risk (commercial, environmental and social), and potential for fire to damage these values, is then performed. Values at risk comprise one or more of the following:

- Commercial values
(values with monetary values)
 - Timber – value of trees for production of wood products.
 - Forage – value of grasses and shrubs for animal feed.
 - Water – value of the land's capacity to capture and store water.
 - Wildlife and Fish – value in the utilisation of wildlife including non-consumptive uses.
- Environmental values
(values that can not be quantified monetarily)
 - Wildlife and fish habitat.

- Endangered plants and animals.
- Soils.
- Long-term ecological impacts.

- Social and political values
 - Public safety.
 - Archaeological, historical or other sites.
 - Sustainability of resource base for local communities.

Fire potential is evaluated considering:

- Fire regime
 - Historical role of fire and its impact on vegetation.
 - Historical fire return interval.
 - Recent Fire occurrence (five to ten years).
 - Historical use of fire.
 - Fire cause(s).
- Fire fuel conditions
 - Present vegetation composition.
 - Projected vegetation composition.
- Environmental conditions
 - Past and present climate and seasonal trends.
 - Climatic change.
 - Topography.

Once the values at risk and the fire potential are identified, the effects of fire on these values can be evaluated. This can be achieved by evaluating values against increasing levels of fire intensity, as in the following example (Table 9.1).

Table 9.1. Values vs. fire intensity levels.*Value Changes per hectare in US Dollars*

Values at Risk	Fire Intensity Level			
	Low	Medium	High	Very High
Timber	- \$100	- \$200	- \$670	- \$1,800
Forage	+ \$20	+ \$10	- \$0	- \$10
Net Value Change	- \$80	- \$190	- \$670	- \$1,810
Historical Site	No damage	No damage	30% destroyed	70% destroyed

In this example, values can include losses and benefits. Note that under a low intensity fire \$100 per hectare is lost, but \$20 is gained in forage value for a net loss of \$80 per hectare. The above information should be developed with the help of ecologists, foresters, local leaders and other stakeholders.

The next step is to determine what level of protection is required. The reason for this step is two-fold. First, it provides an estimate of the protection required, both for the area and for the entirety of all areas protected. Secondly, it provides guidance to fire managers when a fire actually occurs. Typically, fire protection objectives are limited to a small range as shown in the example in Table 9.2.

Once protection objectives for each area have been established and agreed to, the next step is to decide how to implement them.

9.1.3 Selecting Implementation Alternatives

Implementation of the protection objectives is done in a rational manner. Alternatives are developed and evaluated to provide a complete range

of reasonable choices that address the protection objectives and issues. One of the primary means of evaluation is the measurement of the alternative's economic efficiency. This method balances costs with losses due to fire. The costs included in this method are:

- *Budgeted* – these include all the fixed annual costs of maintaining a fire organisation, such as staffing, equipment, training, facilities, etc.
- *Suppression* – these include emergency costs, above the budgeted costs, used to pay for actual fire suppression.
- *Net Value Change* – this is cost of resources lost due to fire.
- *Cost + Net Value Change (C+NVC)* – this is the sum of the above costs, which indicates the overall efficiency of the alternative.

Alternatives are evaluated separately and against one another by varying the organisation's fire suppression capability (crews, equipment, etc.) and therefore its budgeted costs. A larger fire suppression capacity costs more but it can keep

Table 9.2. Guidance of fire protection objectives.

Protection Objectives Example

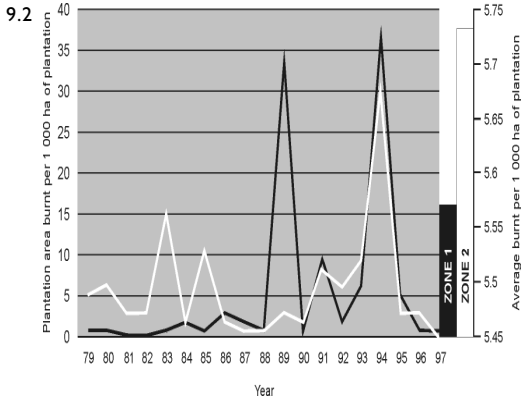
Level	Description
Critical	Fire in any form is not desired at all. Fire has never played a role in the ecosystem or – because of human developments – can no longer be tolerated without significant economic loss. Virtually all fires would be actively suppressed.
Full Protection	Fire plays a natural role in the function of the ecosystem but – because of resource concerns and potentially high economic impacts from fire – considerable constraints exist. Fire suppression is usually aggressive.
Limited Protection	Fire is a desirable component of the ecosystem. Certain ecological/resource constraints may be applied. These constraints – along with health and safety, etc. – are used in determining the appropriate suppression tactic on a case-by-case basis.
Fire Use Area	Fire is desired to achieve the resource condition, sought for designated areas with no constraints. Prescribed fire is used to obtain the desired resource/ecological condition.

fires small and therefore possibly result in a reduction in total costs ($C + NVC$). Conversely, a smaller capability with its lower annual costs might actually cost more if fires become larger, resulting in increased suppression cost and loss of resources. Once a range of alternatives has been developed, the optimum level can be discerned by looking at the alternative with the lowest overall costs ($C + NVC$) as shown in Figure 9.3.

The process of evaluating fire protection alternatives takes time and this text only describes its basic concepts. However, there are considerable advantages in using this type of analysis for building and maintaining a protection capability.

This type of analysis:

- Clearly demonstrates the relationship between the proposed alternatives and their consequences.
- Allows for the most economically efficient programme to be implemented.
- Allows for input and buy-in from stakeholders, critical staff, government officials and political leaders.
- Helps maintain stable funding for fire protection.

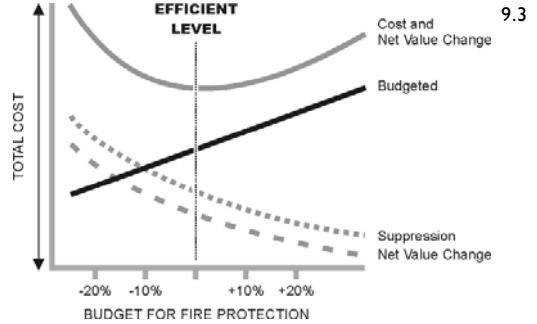


9.2 REGIONAL INTEGRATED FIRE PROTECTION

9.2.1 Regional Phase

9.2.1.1 Evaluating Wildfire History

In South Africa, to some degree all the forestry companies collect information on fires in their plantations, but this is not done at a national, co-ordinated scale. The information on areas damaged and number of fires over a period of time is normally reported to area, regional and head offices. The information is collected in order to satisfy internal (within company) requirements, to determine efficiency of operations and external (e.g. insurance company) requirements. The forestry industry is well equipped to provide this type of information, and each company has a prescribed way of completing this data in order to satisfy these demands. However, this information is not yet stored in such a way that it can easily be analysed or linked to other systems, such as GIS data and additional weather data. Since 1968 the Department of Water Affairs and Forestry (DWAF) in South Africa has requested wildfire



information on a voluntary basis from individual landowners, and has published the collected material in an annual report called "Report on Commercial Timber Resources and Primary Processing in South Africa". Evaluating wildfire history, the inter-relationship between weather, fire suppression at the time of the fire and environment effectively, plays a significant role in establishing the necessary actions which are needed to prevent and suppress wildfires. It is critical that a greater effort is made in gathering this data in order to determine the causes, and optimal suppression and prevention methods.

Financial implications

The South African forestry industry spends an estimated US\$15.41 per hectare planted on fire protection and insurance, which includes keeping watch, standby duty, maintaining equipment, fighting fires and insurance costs (Forests Economic Services, 1998). With a planted area in South Africa of about 1.3 million hectares, the amount spent in this country on fire protection and insurance thus amounts to approximately

Figure 9.2. Protection Areas (M.F. Calvin).

Figure 9.3. Alternative comparison of C+NVC (M.F. Calvin).

US\$20 million. To put these figures in perspective, the total cost of production of timber to roadside (which includes harvesting costs) amounts to US\$167.50 /ha. Fire protection and insurance therefore makes up a total of 9.2% of the total costs of production. The net cost value of the damaged forestry area amounts approximately to US\$625 /ha. Therefore, the financial implications for the owner of the plantation and stakeholders who are dependent on the resource for further processing, are substantial. Since 1979, about 10 800 ha of industrial plantations have been

damaged annually in South Africa, resulting in a loss (in financial terms) of approximately US\$6.75 million per annum.

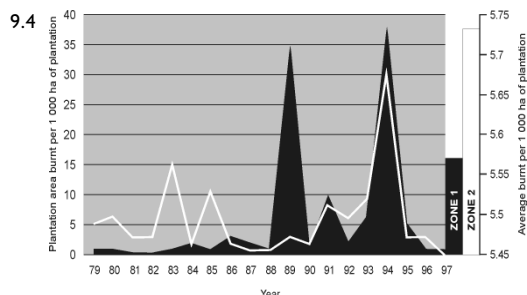
Although fire protection operations reduce the occurrence of wildfires, they do not protect industrial plantations completely. History has shown that – even in the absence of man – nature does not allow fuel to accumulate indefinitely, and wildfires have occurred throughout living memory.

The incidence of wildfires increased as forestry regions became more densely populated. As fuel accumulates in plantations, so fire hazard will

Table 9.3. Zones in South Africa, and plantation area (ha), using 1979 as base year.

Zone	Area (Province*)	Plantation area (ha)
Zone 1	Northern Transvaal (Limpopo)	57 607
Zone 2	Eastern Transvaal (Mpumalanga Escarpment)	273 507
Zone 3	Central Transvaal and Orange Free State (Central Mpumalanga and Free State)	17 845
Zone 4	South-eastern Cape	280 038
Zone 5	Maputoland	23 843
Zone 6	Zululand	129 915
Zone 7	Natal Midlands	194 144
Zone 8	Northern Natal	71 096
Zone 9	Southern Natal	109 618
Zone 10	Eastern Cape	47 333
Zone 11	Southern Cape	77 943
Zone 12	Western Cape	24 318
Total area		1 307 207

* New zone names are in brackets



increase, and even the best fire protection systems can fail.

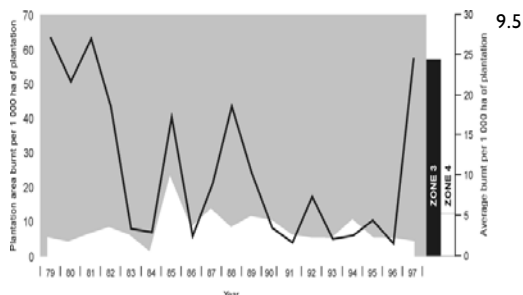
Fire history

For the purpose of analysing fire history in South Africa in this chapter, central statistics of the Department of Water Affairs and Forestry were used. The figures are published annually. This fire data is given for different zones for South Africa. These zones are listed in Table 9.3.

For the purpose of this evaluation, the different zones have been grouped as follows:

- Northern and Eastern Transvaal – zones 1 and 2 (Limpopo and Mpumalanga Escarpment)
- Central Transvaal, Orange Free State and South-Eastern Transvaal – zones 3 and 4 (Central and South-Eastern Mpumalanga and Free State)
- KwaZulu-Natal – zones 5 to 9
- Eastern Cape, Southern and Western Cape – zones 10 to 12

Reporting only the number of fires and area damaged will give an incomplete picture regarding the nature and scope of the fire risk.



Statistics of total area burned and total number of fires in South Africa have little meaning without further information and analysis of, for example, fuel type, climatic conditions, human factors and terrain classification.

Zones 1 and 2: Northern and Eastern Transvaal (Limpopo and Mpumalanga Escarpment)

The statistics of plantation area burned, per 1000 ha of plantation, is given in Table 9.4.

From Figure 9.4 and Table 9.4 it is clear that the averages for Northern and Eastern Transvaal are close to equal, although the Northern Transvaal experienced more severe fires in 1989 and 1994 than the Eastern Transvaal.

Zones 3 and 4: Central Transvaal, Orange Free State and South-Eastern Transvaal (Central, South-Eastern Mpumalanga and Free State)

On average, the Central Transvaal had a larger area burned per annum than the Northern and Eastern Transvaal, but the first has a much lower fire risk than the South-Eastern Transvaal. With 25 hectares of plantation per 1000 hectare of plantations burning per annum, the fire risk can be considered as very high (Table 9.4. and Figure 9.5).

Figure 9.4. Graphical illustration of plantation area burned per 1 000 ha of plantation in Northern and Eastern Transvaal (Northern Province and Mpumalanga Escarpment).

Figure 9.5. Graphical illustration of plantation area burned per 1 000 ha of plantation in the Central and South-Eastern Transvaal (Central and South-Eastern Mpumalanga and Free State).

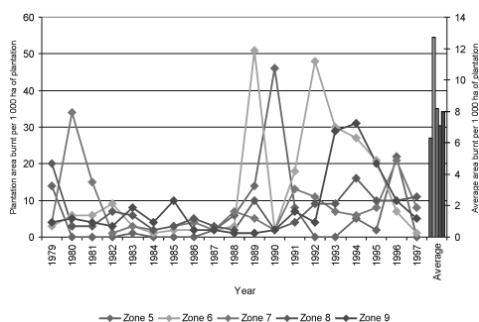
Table 9.4. Plantation area burned per 1000 ha of plantation in Northern, Eastern, Central and South-Eastern Transvaal.

	Northern Transvaal (1)	Eastern Transvaal (2)	Central Transvaal (3)	South-Eastern Transvaal (4)
1979	1	5	63	5
1980	1	6	50	4
1981	0	3	62	6
1982	0	3	43	8
1983	1	14	8	6
1984	2	2	7	1
1985	1	10	40	22
1986	3	2	6	8
1987	2	1	21	13
1988	1	1	43	8
1989	33	3	24	11
1990	1	2	8	10
1991	9	8	4	6
1992	2	6	17	5
1993	6	9	5	5
1994	36	28	6	10
1995	5	3	10	5
1996	1	3	4	5
1997	1	0	57	4
Average	5.57	5.73	25.16	7.47

Table 9.5. Plantation area burned per 1000 ha of plantation in the KwaZulu-Natal area.

	Maputo- land (5)	Zulu- land (6)	Natal Midlands (7)	Northern Natal (8)	Southern Natal (9)
1979	14	3	4	20	4
1980	0	6	34	3	5
1981		6	15	3	4
1982		9	1	7	3
1983	1	3	3	6	8
1984		1	2	2	4
1985		2	3	3	10
1986		2	4	5	2
1987	2	2	2	3	2
1988	6	3	7	2	1
1989	14	51	5	10	1
1990	46	2	2	2	2
1991	8	18	13	4	7
1992		48	11	9	4
1993	0	30	7	9	29
1994	5	27	6	16	31
1995	2	21	8	10	20
1996	22	7	21	10	10
1997		1	8	11	5
Average	6.3	12.7	8.2	7.1	8.0

9.6



Zones 5 to 9: KwaZulu-Natal (this combined region consists of Maputoland, Zululand, Natal Midlands and Northern and Southern Natal)

From Table 9.5 it is evident that Zululand experienced severe fires during 1988 to 1995, although, on average, fire occurrence is still much lower than in the South-Eastern Transvaal. The fire history in other areas in KwaZulu-Natal compares favourably with the Transvaal regions.

Zones 10 to 12: Eastern, Southern and Western Cape

Especially in the Western Cape region, it is obvious that the data published by the Department of Water Affairs and Forestry is inaccurate. With SAFCOL being the largest plantation landowner in this region, the SAFCOL plantation data clearly points out the following major fires over the statistical period used:

December 1994:

La Motte plantation – 653.1 ha

February 1996:

Jonkershoek plantation – 386.3 ha

February 1997:

Tokai (Lourensford) plantation – 950.7 ha

None of these areas were included in the Government data, and if only these three fires were included the average burned area would increase from 8.57 to 12.93 ha per 1000 of plantation for the Western Cape. In the Southern Cape, some major fires occurred in SAFCOL plantations, which were also not included in the Government's fire data published. Although it is in this case not as serious as in the Western Cape, it still provides a much lower risk than was in fact experienced.

Although the data may not be complete, it still provides a valuable insight into the plantation area burned over the past two decades.

One of the conclusions arrived at, is that fire danger periods follow a particular pattern as a result of cyclical weather patterns. Therefore, national and local FDI predictions are critical in establishing such patterns to predict forthcoming high-risk periods. All fire suppression and detection should be focused on these high-risk periods.

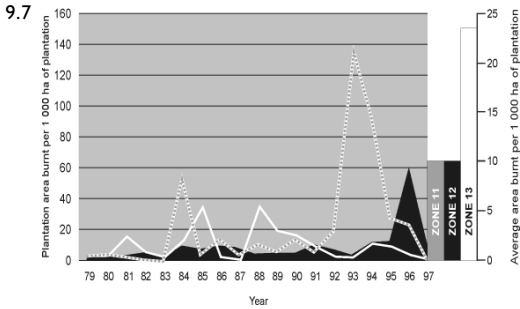
Secondly, it is clear that the Northern Province (Northern Transvaal) and Mpumalanga Escarpment (Eastern Transvaal) experienced the least fire damage over the 19-year period. This information can be used for negotiating lower insurance premiums or to allocate resources.

Thirdly, there is a need for the keeping of centralised, accurate fire data, as all strategic planning should be based to some degree on historical data. Unfortunately there is no incentive for landowners to provide this kind of information. As membership to the Fire Protection Associations (according to the new Veld and Forest Fire Act No. 101 of 1998) is voluntary in South Africa, this will also not ensure access to accurate fire data. As the world moves further into the information

Figure 9.6. Graphical illustration of the plantation area burned per 1000 ha of plantation, in Maputoland, Zululand, Natal Midlands, Northern Natal and Southern Natal.

Table 9.6. Plantation area burned per 1000 ha of plantation in the Eastern, Southern and Western Cape.

	Eastern Cape (11)	Southern Cape (13)	Western Cape (13)
1979	3	1	3
1980	4	0	3
1981	2	0	13
1982	1	2	5
1983	1	0	2
1984	49	5	11
1985	5	4	29
1986	12	5	3
1987	4	2	1
1988	9	1	28
1989	5	3	16
1990	11	2	14
1991	5	6	8
1992	16	4	3
1993	135	0	2
1994	76	7	9
1995	23	8	8
1996	20	44	4
1997	1	0	1
Average	20.1	4.94	8.57



age, information system management will play an ever-increasing role in the analysis and interpretation of data. Systems will not only be designed to capture and analyse specific data, but will also be able to link this data to other systems so that in-depth analysis can be applied to ensure that the occurrence of wildfires is understood and that preventative actions can be in place before these devastating fires take place.

9.2.1.2 Establishing Fire Protection Objectives

Fire protection objectives for a specific region are dependent on aspects such as natural vegetation cover, land use, population distribution and density, topography and climate, as well as the history of wildfires and wildfire hazard. All these aspects are unique for each major region, and should (firstly) be considered as a broad regional fire protection strategy before fire hazard is mapped, or any decisions are made regarding major fire protection units, their routes and specifications. The size of a region for the purpose of fire protection will depend on the uniqueness of such an area with regard to the above-mentioned aspects, and regional boundaries should be

considered carefully where no such fire protection region has been identified and described in the past. However, it is important to note that each fire protection region should first be clearly demarcated before fire protection objectives are considered. Some fire protection regions may only consist of a relatively small area (such as the high winter rainfall region of the Western Cape), while others may consist of much larger areas (e.g. Kalahari woodland, covering vast parts of various southern African countries). However, procedures to set regional objectives should follow the same principles.

It is particularly the natural vegetation cover (e.g. montane grassland or savanna) and land use (e.g. for sheep farming or forestry) that will determine which fire protection strategy should be followed; but these aspects are in most cases significantly influenced by aspects such as weather patterns (e.g. main fire season and main direction of dangerous wind) as well as population spread (e.g. population density, sites of informal settlements and potential urban-interface problems). These aspects – together with the wildfire history of the region – will form the basis for the region fire protection strategy (De Ronde, 2000a; 2000c).

The fire protection strategy should be incorporated into the regional fire protection plan, and should be concisely compiled to cover important issues of fire protection at a regional level such as:

- Fire hazard evaluation and identification of hazardous areas.
- External and internal fire protection strategy including regional bufferzoning.

Figure 9.7. Graphical illustration of the plantation area burned per 1000 ha of plantation in the Eastern, Southern and Western Cape.

- Control over fire protection programmes.
- Disaster management.

Care should be taken that issues such as ecological prescribed burning restrictions, optimal water supply maintenance and urban interface problems or potential problems are carefully considered when the regional fire protection strategy is drawn up.

9.2.1.3 Regional Fire Hazard Mapping

Before fire hazard can be considered at regional level, it is necessary to classify fire hazard according to a specific fire hazard grading system. When regional fire hazard classifications are used (which vary according to the nature and percentage cover of natural fuels and land-use) it may be necessary to base this mainly on natural vegetation cover features, man-made fire hazard features, or a combination of both. Region-specific classifications should thus be developed after careful evaluation of requirements.

A typical classification, developed for the Melmoth district of the KwaZulu-Natal Province, South Africa (where industrial plantation forestry and sugar cane growing form the main land use), is provided as illustration (De Ronde, 2000a):

- A Extremely high fire hazard (red)
 - A1 Montane grassland not annually burned.
 - A2 Unmanaged *Acacia* (Wattle) jungle.
 - A3 Rural settlements located on the dangerous, wind-exposed (mainly W and N), side of industrial plantation boundaries.

- B High fire hazard (orange)
 - B1 Irregularly burned wetlands.
 - B2 Montane grassland burned annually, but during the fire season.
 - B3 Plantations consisting mainly of *Eucalyptus* stands.
 - B4 Areas adjoining rural settlements, situated at lower altitude along the S and E boundaries.
- C Medium fire hazard (yellow)
 - C1 Wetlands annually burned before the fire season.
 - C2 Plantations consisting mainly of *Pinus* species.
 - C3 Rural settlements situated on the less dangerous leese (mainly E and S) of plantation boundaries at similar (or higher) altitude.
 - C4 Montane grassland, burned annually before the fire season.
- D Low fire hazard (green)
 - D1 Areas adjoining well managed *Acacia* plantations.
 - D2 Annually cultivated and well-maintained (ploughed) land.
 - D3 Mechanically prepared and sown grazing camps.
 - D4 Areas adjoining sugar cane compartments.

The fire hazard classes should be described in the strategic fire protection plan and should be mapped on 1:50 000 topographical (regional) fire protection maps that cover the region (De Ronde, 2000a).

9.2.1.4 Regional Bufferzoning

On-site studies, wildfire simulation, topographical terrain considerations and wind flow dynamic studies – together with wildfire history studies (see 9.2.1.1) – should be used to consider where in the landscape major regional fire breaks (bufferzones) should be placed. Also important is to determine what their specifications should be, and how they should be placed in the landscape in relation to the most dangerous wind direction (De Ronde, 2000a). These zones will disregard man-made property boundaries and provide continuous protection lines which can stop most (if not all) wildfires, or at least provide safe lines from where counter-fires can be applied against approaching wildfire fronts. The following main criteria have to be considered when bufferzones are placed:

- To incorporate natural protection features as much as possible, such as watersheds, constantly flowing rivers and indigenous forests.
- Include major roads, suitable prescribed burning areas/compartments (natural as well as plantations) and cultivated lands.
- Incorporate recent wildfire areas.
- Place the zones (as near as possible) at a 90° angle with the most likely direction of maximum fire spread.
- Ensure that the buffers form continuous lines from the safest possible starting to ending points.
- Provide adequate width along favourable topography, from where a counter-firing line can be constructed, from where an approaching wildfire can effectively be attacked.

Bufferzones should also be mapped on the 1:50 000 regional fire protection maps, and must be described in detail in the strategic regional fire protection plan. All land owners and fire fighting organisations within the region should have full detail available about these regional bufferzones and fire fighting should (where possible) be concentrated along these lines.

9.2.1.5 The Strategic Fire Protection Plan

Certain realities are here to stay, which should be considered in developing an integrated fire protection plan:

- Increased population pressure and subsequent increase in fire hazard as more and more people infringe on the natural and plantation environment.
- Global changes in weather patterns will have to be accepted as a fact and planners will have to consider these issues in future seriously.
- Urban interface problems must be identified, and an action plan has to be developed by local authorities.
- Weed control programmes on a regional level must be implemented to address factors such as biomass accumulation (and subsequent fire hazard).
- Continuous attempts are necessary to come as close as possible to optimum ecological requirements. In grassland and in fynbos, in particular, realistic compromises with regard to the ecological burning programme must be made to reduce the wildfire hazard to acceptable levels.

A fairly new approach to fire protection of industrial plantations has been developed into a cost-effective vehicle that provides a dynamic buffer-zoning system, which reduces wildfire hazards significantly and also provides an effective base for fuel management (De Ronde, 2000a). The aims of a strategic fire prevention plan are:

- Fire hazard reduction and improved fire-break placement.
- Stopping major external wildfires.
- Containing fires within the plantations.
- Improved fire management in residential/plantation interface.

This can be achieved by making use of regional fuel and fire behaviour modelling, fuel classification and fire hazard rating at both regional and plantation level, and selective use of prescribed burning. Furthermore, the integration of riparian zones and nature conservation programmes into fire protection systems results in multi-purpose bufferzones.

Integration with conservation programmes

Priority areas deserving special conservation status, such as unique floral communities, breeding areas for rare animals and special cultural sites, must be considered for incorporation as part of bufferzones (De Ronde, 2000b). The creation of natural corridors throughout such areas will be facilitated in this way, by following main riparian zones and inter-connected internal bufferzones (De Ronde & Masson, 1998).

Multi-purpose strategic regional plan

A strategic fire prevention plan may form part of an integrated fire management plan, which includes the following aspects (ITTO, 1997):

- Fire prevention
- Fire pre-suppression
- Fire suppression
- Training and education
- Law enforcement and the use of incentives
- Prescribed burning for special purposes

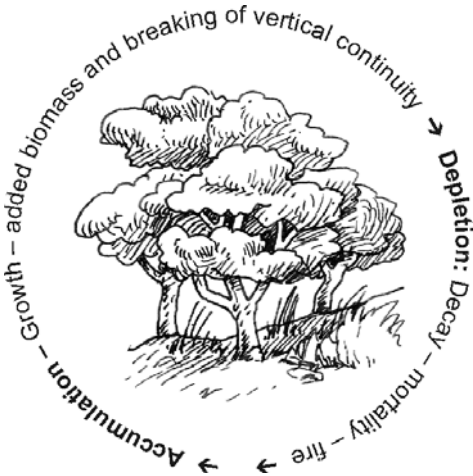
Addressing urban interface problems

Much of the responsibility for implementing a good comprehensive and effective plantation/urban interface fire protection programme is going to fall on local government and municipalities.

The location of homes and other buildings in, or adjacent to, fire-prone areas of vegetation can have the following effects:

- The risk of loss of life and property is greatly increased.
- Fire fighters are often put in exceptionally dangerous situations as they are forced to protect property.
- Fire commanders could shift tactics towards structure protection and away from controlling the main fire.
- Potential conflicting priorities in fire management policies where public and private land meet.

9.8



The fuel models developed with BEHAVE made it possible to arrive at a site-specific fuel classification that can be applied at an individual compartment basis. The actual present and predicted fire hazard status can be mapped and evaluated by identifying high, and extremely high, fire hazard areas and any shift in the hazard status over time.

9.2.2 Evaluation Phase

9.2.2.1 Fuel Modelling, Fuel Classification and Fire Hazard Rating

To arrive at a suitable fuel classification database at a smaller scale (1:10 000 to 1:30 000) it is necessary that the fuels of all significant burnable areas in the region are considered for fuel modelling to arrive at a representative fuel model file. This

process can be regarded as the first step towards fire hazard assessment at a more detailed level, which can be used during the evaluation process. In some cases (such as in regions where natural fuels dominate) it may be necessary to subdivide fuels according to age classes or major topographical/ climatic features; while in the case of agricultural land, single fuel models may be sufficient to represent a certain fuel (such as sugar cane, maize lands and grazed grasslands). In the case of industrial plantations, a sub-division by age/species is normally required (De Ronde, various regional fuel model files).

Fuel models should be developed and tested with the NEWMDL and TSTMDL modules of BEHAVE (Burgan & Rothermel, 1984), and fire behaviour characteristics must also be further illustrated with the assistance of certain BehavePlus options (e.g., SURFACE). This will make it possible to rank these fire parameters according to standardised performance for typical wildfire conditions:

- Flame Length (m)
- Rate of Spread (m/min)
- Fireline Intensity (kW/m)
- Heat per Unit Area (kJ/sq.m.)
- Maximum Spotting Distance (km)

A typical ranking outcome – as arrived at in the Melmoth District in the KwaZulu-Natal region of South Africa – is provided in Table 9.8.

Classifying the fuel models according to their

Figure 9.8. Fuels increase and decrease over time as a result of interacting processes.

Table 9.8. Fire behaviour ranking classes*.

Sub-grading **	Low fire hazard	Medium fire hazard	High fire hazard	Extremely high fire hazard
+	11-15	26-30	41-45	>45
▪	6-10	21-25	36-40	
-	0-5	16-20	31-35	-

* Total of individual ranking values of each of the five fire parameters as provided above.

** These sub-gradings (+, ., -) provide sub-classes for each main ranking class (low to extremely high fire hazard). This also applies to Table 9.9.

ranking sum produced the following results in this example (Table 9.9).

A ranking process of this nature will now make it possible to arrive at a fuel classification that can be used as a basis for fire hazard rating after adjusting the fuel classes for static fire hazard

features other than fuel characteristics (such as distance from public roads, rural settlements and irregularly-burned grassland, positive aspects such as adjoining riverine or mountain forests, prominent watersheds or ploughed agricultural land). Table 9.10 illustrates the adjustments used

Table 9.9. Fuel model allocation in classes, according to their fire behaviour ranking sum, for the Melmoth district.

Sub-grading **	Low fire hazard	Medium fire hazard	High fire hazard	Extremely high fire hazard
+	1-yr-old Pine 1-yr-old Eucalyptus 1-yr-old Acacia		> 2-yr-old Grassland Eucalyptus slash 0- to 1-yr old	3- to 5-yr old Pine (++ sub-grading)
▪	1-yr-old Grassland	> 4-yr-old Eucalyptus	Pine slash 0-to 1-yr old Acacia slash 0-to 1-yr old 2-yr-old Grassland 2- to 4-yr-old Acacia	
-	Overgrazed grassland > 4-yr-old Acacia Sugar cane	> 5-yr-old Pine	2- to 4-yr-old Eucalyptus 2-yr-old Pine	

Table 9.10. Fire hazard adjustments used to arrive at fire hazard ratings for the Melmoth area.

Adjustment*	Detail
+3	Montane grasslands not annually burned, along W and N property boundaries.
+3	Unmanaged Wattle jungles along W or N property boundaries.
+3	Rural settlements situated on dangerous, W and N property boundaries.
+2	Montane grassland not annually burned along E and S property boundaries.
+2	Areas adjoining main public roads/railway lines.
+2	Areas adjoining rural settlements situated at lower altitude along S or E boundaries.
+1	Compartments adjoining power lines.
+1	Montane grassland not annually burned (or burned yearly, but during the dangerous fire season) adjoining E or S property boundaries.
+1	Well managed Pine or Eucalyptus plantations bordering property boundaries in W and N.
+1	Rural settlements situated at same or lower altitude along E or S property boundaries.
.	Well managed Pine or Eucalyptus plantations bordering property boundaries in the E and S.
.	Montane grassland or wetland along W or N property boundaries, burned annually before the fire season.
-1	Areas adjoining overgrazed tribal land.
-1	Areas adjoining sugar cane compartments.
-1	Areas adjoining well managed, mature, Wattle plantation.

for the Melmoth district.

Fire hazard ratings should then be calculated per compartment to illustrate the existing as well as future predicted fire hazard status three to five years from now (De Ronde, 1990).

9.2.2.2 Mapping Fire Hazard over Time

A suitable base map (or maps) should be selected to act as fire hazard rating maps, which should be at the smallest possible scale without having to use more than one or two maps per rating year. In the case of smaller plantation units a scale of 1:10 000 may be sufficient, but in most cases a

scale of 1:20 000 or 1:30 000 will be best for nature reserves, agricultural districts or large industrial plantation areas. Where little variation is present on e.g. larger plains, a scale of 1:50 000 may prove to be adequate. Two maps should be prepared (coloured-in or with GIS assistance if possible) to illustrate fire hazard. One to show the existing hazard situation, and one the future (predicted) hazard status. Colours recommended are green, yellow, orange and red to illustrate the main hazard classes, while for sub-gradings (Table 9.9) different colour patterns within the main colour groups/hazard ratings can be used (De Ronde, 1990). When comparing the two (sets) of maps – one for the present and one for the future fire hazard status – prominent high fire hazard areas and major shifts in hazard can easily be identified and then be considered in the following decision-making process (placement of fire protection systems such as fire breaks):

9.2.2.3 Evaluating Existing Fire Protection Measures

Based on the fire hazard rating phase, long-, medium- and short-term programmes are put together. In this process some of the issues that must be addressed are:

- The placement of existing fire belts.
- Riparian zone requirements.
- Nature conservation requirements, such as special regimes for natural heritage sites, wetlands, etc.
- Financial constraints and the cost-effectiveness of the recommendations.
- Adjustments required in the working plan

and changes to silviculture and harvesting policies.

This process follows immediately after the fire hazard rating evaluation process described in the above paragraphs, and starts off with a detailed inspection on the ground, sometimes with the assistance of aerial studies. During this evaluation process, carried out in the company of managers responsible for fire protection in the area, all fire protection systems should be visited and rated according to their effectiveness and possible (better) alternatives. The basis for these decision-making procedures will be the already-placed regional bufferzones, which will now have to be planned in more detail at a smaller scale, as well as the outcome of the fire hazard evaluation programme. All aspects – such as ecological requirements, financial constraints and fuel management programmes other than for fire protection – will have to be considered. In some cases it may be necessary to re-simulate wildfire along specific fire breaks or zones to double-check on optimum fire break routes and specifications until all involved are satisfied that the best option has been adapted.

9.2.3 Application Phase

9.2.3.1 Placing Bufferzone Systems

Although it was decided during the Regional Phase where the main bufferzones should be situated in the landscape at the (larger) 1:50 000 scale, there still remains a lot of work to be done at a smaller (more detailed) level to determine exactly where the boundaries of these zones

should be. This finer detail of this programme can only be dealt with after completing the Evaluation Phase (see 9.2.2), and once the broader-scale routes of zones are considered at smaller-scale maps. This will provide more detail regarding tree stands or compartments (in the case of industrial plantations), grazing camps (in agriculture) and the fuel mosaic pattern or wildfire history (in nature reserves and mountain catchment areas).

Where a lack of fuel management options or prescribed burning restrictions occur, alternative routes may (temporarily) have to be considered, until such time that the fuel status of these areas are more favourable for fuel reduction/fire application. More exact (final) route placement may also give rise to minor deviations of bufferzone boundaries and routes.

Apart from the major regional bufferzones, other bufferzones – such as internal bufferzones – can now also be placed and described, with the emphasis on natural protection lines (such as wetlands) and artificial alternatives (such as public roads and areas with restricted fuel levels). The main aim here will be to reduce the area at risk within management units, and to fill gaps in the creation of continuous fire protection lines.

9.2.3.2 External Fire Protection

Requirements

Once the bufferzone systems have been placed in the landscape, attention should be given to other external fire protection, property boundaries and management units such as plantation blocks. In most areas in the summer rainfall region the main objective should be to provide maximum pro-

tection on dangerous western and northern boundaries in whatever way this can be done economically. Yearly burning of grassland still remains one of the most viable options in southern Africa, particularly where these fire protection units are bordering densely populated rural settlements, wattle jungles, irregularly-burned grassland or *Eucalyptus* plantations, with accumulated forest floor and slash levels.

In many cases attempts will have to be made to strengthen yearly prepared fire breaks with fuel-free plantation roads, tree compartments (bordering external fire breaks) that were clearfelled and slash-burned, or so-called “prescribed burning chains” (lines of prescribed burning compartments in industrial plantations) to ensure maximum protection along dangerous boundaries.

In contrast, along eastern and southern boundary lines, only minimal fire protection should be provided, unless these are bordering dangerous fuels or hazardous land. A single burned tracer line may sometimes prove to be adequate for protection (actually just to mark the boundary), while plantation roads can be utilised to advantage in the same manner to ensure maximum protection at minimum cost along these lines.

9.2.3.3 Reducing the Area at Risk

This applies to the area within external boundaries and can include industrial plantations with compartments/blocks or farms subdivided into different camps/cultivated lands. It can also be applicable to sub-divided nature reserves, hunting farms, rural areas, mountain catchment areas or other forms of natural grassland, bush or forest.

It is important that the area at risk within a fire management unit is reduced as much as possible to restrict free spread of wildfires, which either originated within the unit or from outside its boundaries. This can be done by identifying effective, continuous, fire protection lines, which can be used as part of the internal fire protection system. Natural protection lines should be used for this purpose where possible, extending them with additional fire break sections where these lines are not continuous, or present where they present gaps. In natural vegetation, existing wetland lines, rivers, mountain ridges and road systems should be used to advantage where possible to achieve this.

To calculate the results of internal fire protection improvement, the area of individual areas at risk should be calculated (in ha) before and after fire protection adjustments have been applied, to arrive at an average area at risk before and after improvement measures. This comparison can also be used to advantage to see if any of the larger units may require further attention to reduce the risk area(s).

9.2.3.4 Prioritising Prescribed Burning Programmes

In many cases prescribed burning programmes can only be completed if long burning seasons are experienced with a maximum number of suitable prescribed burning days. Unfortunately, during some years, only a restricted number of suitable burning days can be used, particularly if the rains dry up earlier (during autumn in the summer rainfall area, or in spring in the Western Cape province of South Africa), and subsequently

moisture stress and frost provide more available (burnable) fuel, with drier conditions much earlier than expected. Unseasonal showers, late during the burning season, may also cause further prescribed burning days restrictions. It is thus of the utmost importance that prescribed burning is applied in a certain sequence, and according to set priorities.

In the summer rainfall regions, in areas dominated by natural (dynamic) grassland, the following burning priorities are normally used (De Ronde, 2000a):

- Main (regional) bufferzones (always the top priority).
- External fire breaks on dangerous (N and W) boundaries.
- Fire protection along public roads.
- Fire protection under powerlines.
- Internal bufferzones.
- Fuel management around internal settlements and houses.
- External fire breaks along less dangerous (E and S) boundaries.
- Other conservation burning programmes.

9.2.3.5 Fire Protection Plan Maintenance

It is recommended that fire protection plans are checked and adjusted annually. It is also important that all major wildfires that have occurred are mapped annually on fire protection maps, and that prescribed burning programmes are adjusted accordingly. This applies equally to the regional maps (1:50 000) as well as more detailed fire protection maps and year plans. Progress with longer-term strategies can then also be checked

where necessary, while – in the case of industrial plantations – the effect of the past 12 months' clearfelling and slash burning programme can also be considered. Actual number of fire breaks prepared, versus those planned for that specific year, should also be checked and future plans should be adjusted where necessary.

9.3 Other Fire Prevention Measures

9.3.1 Studying Wildfire Causes and Risk

Effective fire prevention begins with the identification of problem areas. The exact causes of fires are of great importance since management's actions must address them in order to reduce the risk and impact. Unlike in other parts of the world, where a large percentage of fires are of natural origin (especially lightning), the southern African forestry environment is marked by a prevalence of human-induced fires.

Natural causes of fires represent only a small percentage of all fires in SAFCOL plantations (4.5–10.6%), depending on the geographic area. It is difficult to study old records on fire causes as statistics on fires plantation areas were often combined with fires occurring in mountain catchment and indigenous forest areas.

Wildfire causes

The identification of the cause of problem fires is not as simple as it seems, and although statistics may assist, they are limited, by the accuracy of the fire investigation, and by the processing thereof. Forest fires, started in other ways than by natural causes, may be classified according to the degree of culpability of the person responsi-

ble as malicious, wilful, negligent and accidental (Gordon, 1955).

Malicious fires. Malicious fires, or arson, is a felony and are not usually dealt with by the forest laws, but under the general criminal law of the land. Forest arson can be carried out in isolated areas where the presence of chance witnesses is unlikely, so that offenders are rarely caught.

Malicious fires are sometimes set for revenge, and the prospect of retaliation by incendiarism may profoundly influence the methods by which a forest policy can be carried out. Such fires have been started through the concerted action of a community protest against unpopular measures, or on account of real or imaginary grievances of an individual against the forest or member of the forest staff.

In times of unemployment, malicious fires may be set with the object of creating work and trade through harvesting of burned timber, or even in order to obtain wages from putting out the fire. Where grazing is permitted within a forest area, fires are sometimes set with the object of improving the pasture.

Wilful fires. The expression wilful is used to cover conflagration started deliberately, but without an intention to destroy property. Such fires are commonly started in pursuit of game, to improve the grazing or for the collection of honey.

Negligent fires. This term is used to distinguish cases where the fire itself has been deliberately lit, but its subsequent spreading was not intended. Instances are camp and cooking fires, cigarette

ends and casual matches.

Accidental fires. Fires are said to be truly accidental where neither the original fire nor the subsequent conflagration can be attributed to the deliberate act of any person.

Groupings of causes

Classification of causes into groups will differ from country to country, and between forestry companies. Causes of problem fires can be categorised according to the list of the US Forest Service (see Table 9.11).

Within the forestry industry in South Africa, a standard fire report form is used and fire groupings of causes are as follows:

- Mechanical

- Own burning activities
- Human element
- Natural cause
- Unknown

Table 9.12 provides the complete list of groupings and individual causes as used by the forestry industry.

Accuracy of the primary cause of ignition is important when investigating the fire. With training and experience, the fire investigation officer will be able to state the cause as being “definite” or “probable”. The high number of fires of which the cause is unknown is of concern. As management actions need to focus on specific causes, this category must be investigated in-depth to ensure accuracy. From old South African Depart-

Table 9.11. Grouping of causes of fires.

Equipment	A fire resulting from use of equipment.
Forest Utilisation	A fire resulting directly from timber harvesting, harvesting other forest products except use of equipment, smoking, and recreation.
Incendiary	A fire wilfully set by anyone to burn vegetation or property not owned or controlled by him and without the consent of the owner or his agent.
Land Occupancy	A fire started as a result of land occupancy for agricultural purposes, industrial establishment, construction, maintenance, and use of rights of way and residences except use of equipment and smoking.
Lightning	A fire caused directly or indirectly by lightning.
Recreation	A fire resulting from recreation use except smoking.
Smoking	A fire caused by smokers, matches, or by burning tobacco in any form.
Miscellaneous (Unknown)	A fire of known cause, that cannot be properly classified under any of the other seven standard causes.

ment of Forestry Annual Reports, several causes were identified. These are outlined in Table 9.13.

From the table it can be seen that locomotives caused several fires in the 1960s, while incendi- arism was also a major concern. However, to see what the present situation is, SAFCOL data was used for the past four years. As SAFCOL has com- mercial forestry plantations in both the summer and winter rainfall areas of South Africa, it fairly well represents forestry in South Africa. The causes of fires in SAFCOL plantations – for all South African forestry regions – are provided in Table 9.14.

From the SAFCOL statistics of all plantation fires (Table 9.14), it can be seen that arson con- sistently causes the most fires. What is impor- tant to realise is that these actions are often not directly aimed towards SAFCOL or its manage-

ment, but are a result of local factors, such as civil unrest. To try and address this issue a reward system was implemented for information leading to arrests and conviction. Honey hunters are also a major concern and although some measures are in place at plantation level to identify and remove bees from plantations, they do not seem to be consistently effective.

Fire risk

Fire hazard (risk) varies from country to country according to type of forest, climate and density of population.

Establishing plantations increases the fire hazard in several ways. The plantation tree species are more fire-prone than the vegetation that they replace but, most important, due to dramatic changes in fuel loads the plantations develop and

Table 9.12. Causes of fires: South African forestry industry.

2. Mechanical	3. Own burning	4. Human element	5. Natural cause
21 Train	31 Fire breaks	41 Arson	51 Lightning
22 Chainsaw	32 Brushwood	42 Contractor	52 Static electricity
23 Power line	33 Crop residue	43 Cooking fire	53 Falling rocks
24 Power tool	34 Refuse dump	44 Warming fire	
25 Welding	35 Sugar cane	45 Honey hunters	
26 Blasting	36 Veld/grazing	46 Children	
27 Heavy equipment	37 Flare-up	47 Picnickers	
28 Firearms	38 Trace burning	48 Neighbours	

Table 9.13. Causes of fires: government land (source: DWAF Annual Report).

Cause	1958/59	1959/60	1960/61	Average
Departmental	5.6	3.4	4.3	4.4
Smokers	1.1	3.4	1.3	1.9
Squatters	0.4	2.1	0.3	0.9
Honey hunters	4.5	4.8	4.3	4.5
Trespassers, campers, picnickers	6.7	6.5	4.7	6.0
Arson (incendiarism)	18.7	24.3	17.8	20.3
From adjoining properties	10.5	4.5	13.0	9.3
Locomotives	15.0	25.4	22.3	20.9
Lightning	13.5	11.6	8.7	11.3
Unknown	24.0	14.0	23.3	20.4
Total	100.0	100.0	100.0	100.0

are being utilised (Chandler et al., 1983). Therefore a further analysis was done on the fire statistical data of Table 9.14. As only 60 fires (2.2%) of the total number of fires cause 91% of the total damage (area burned), these fires were analysed separately (Table 9.15).

From the information in Table 9.15, it is clear that most fires came from neighbouring properties, which includes other forestry companies, communal land, agriculture and natural areas such as mountain fynbos. A further classification of the exact cause will be useful in order to address specific problems, even if they occur on neighbouring properties. Arson remains a major cause of fire, as close to 5500 hectare of commercial plantations have been destroyed through this action.

Lightning is also a major concern, although the largest portion of the damage was caused by a few incidents of lightning fires in the Southern Cape mountains. Due to several factors, suppression could not be initiated soon enough and, combined with severe dry bergwinds, caused damage to adjoining commercial plantations.

With this in mind, and the indication that – just from the SAFCOL example – humans caused at least 13 000 ha of damage over a seven-year period, proper prevention measures are critical to reduce the risk and impact of fires. As part of plantation fire risk assessment the following needs to be understood (*NSW Bush Telegraph*, 2000):

Prevention

Table 9.14. Causes of fires in SAFCOL plantations (source: SAFCOL 2000).

Cause	1996/97	1997/98	1998/99	1999/00	Average
Arson	45.9	35.3	27.0	34.0	35.5
Unknown	17.2	6.0	20.0	19.4	15.6
Lightning	10.6	4.5	6.6	7.2	7.2
Honey hunters	9.6	15.7	18.5	4.9	12.1
Neighbours	5.6	9.0	5.9	8.9	7.3
Fire breaks & flareups	2.2	10.8	4.7	4.4	5.5
Power lines	2.0	2.0	1.1	1.7	1.7
Smokers & warming fires	1.8	5.6	6.1	3.6	4.6
Other (e.g. children, contractors, picnickers, roads, chainsaw operations)	5.1	11.1	10.1	15.9	10.5
Total	100.0	100.0	100.0	100.0	100.0

- Modern harvesting practices and equipment reduce ignitions.
- Pruning, thinning and weeding reduces plantation fire risks.

practised.

Response

A rapid, aggressive and sustained response to minimise the area burned.

Preparedness

- Extensive road networks allow quick access to fire.
- Lookouts and electronic fire detection systems permit early fire detection.
- Fleet of adequate fire fighting equipment for quick response.
- Highly trained and well-equipped fire fighting staff.
- Staff and equipment readiness scaled up or down according to fire danger.
- Fire suppression plans regularly reviewed and

9.3.2 Regional Extension Work

Effective control of each source of risk requires knowledge of how each factor operates locally, and when and where fires are most likely to start. As stated by Brown and Davis (1973), “conducting a fire prevention programme without reliable information is like operating a ship without a rudder; it uses up energy but does not get anywhere”.

It is often extremely difficult to get at the real reasons why people start fires (Brown & Davis, 1973). The apparent or stated reason may not be the

Table 9.15. Causes of the 60 major fires in SAFCOL (1994–2000).

Cause internal	Data			
	Total area (ha)	%	Number	%
Arson	5509	18	12	20
Children	2372	8	4	7
Cooking fire	2040	7	3	5
Honey hunters	36	0	1	2
Informal settlement	645	2	1	2
Labour unrest	481	2	1	2
Lightning	3816	13	5	8
Neighbours	10 775	36	17	28
Own burning	1152	4	6	10
Power line	1987	7	4	7
Rubbish dumps	220	1	1	2
Smokers	675	2	3	5
Unknown	580	2	2	3
Grand total	30 288	100	60	100

real one, which may be deeply rooted in anthropological, cultural and psychological patterns and habits. Unless these things are understood, effective progress cannot be made in making people not only forest-fire conscious, but positive in their actions to prevent them. Man-caused fires are commonly ascribed to carelessness, but there are different shades of what is commonly called “carelessness”, such as heedlessness, indifference and thoughtlessness as well as more or less culpable negligence (Brown & Davis, 1973). In all situations, some control of the movement or behaviour of people is required and three broad

categories of measures can be identified:

- Education of the public
- Regulation of public use
- Enforcement of fire laws

Education of the public

According to Brown and Davis (1973), people are the primary problem in the prevention of fires. Education of the public is a primary effort, which may include the following media:

- Books, magazine articles, news releases

- Radio messages
- Television programmes
- Video/film
- Signs, posters, exhibits
- Handouts
- Slide shows and speeches
- Personal contacts

The logic behind prevention programmes is obvious: Money spent on fire prevention can be worth costly fire damages and fire suppression expenses.

According to Chandler et al. (1983), fire prevention needs to take the following into account:

- No forest fire prevention campaign can be successful without general support from the local community.
- Face-to-face communication is the most effective way to change attitudes towards forest fire safety.
- The best prevention communicators are local residents.

Each of these means of communication is effective when skill is used in choosing the right time, place and persons. Underlying is the question of motivation.

Regulation of public use

The regulation of use of forestry land is important in preventing human-caused fires. It is also closely related to educating the public on one hand, and to law enforcement on the other. The most common form of regulation is by the application of closures of various kinds.

Where fire emergency is the only reason,

closures should be limited to fire danger periods. Some of these measures are based on law, others operate as rules and regulations under the general authority of the forest owner or the agency responsible for administration of the land.

Law enforcement

Law enforcement is always a necessary tool in fire prevention. In South Africa, the National Veld and Forest Fire Act, No. 101 of 1998, and the Forest Act of 1998, provide the essential background to law enforcement. However, legal deterrence only becomes effective through active enforcement. One example of a law enforcement measure is the publication of the "prohibition on making of fires in the open air", which is published annually in the Government Gazette for different South African regions.

Regional examples of extension work

Very little extension work has been done in South Africa, except for the old "Bokkie" ("Bambi") signs of the Department of Water Affairs and Forestry, and a few *ad hoc* localised actions aimed at plantation fire prevention.

One example of a specific local project is the "Ukuvuka Operation Fire Stop" project in the Cape Peninsula, Cape Town. Invading alien vegetation is to be cleared from both public and private land along the entire Peninsula mountain chain, from Cape Point to Table Mountain.

This clearing will be combined with the establishment of fire-breaks, block-burning, fire proofing of vulnerable properties and erosion control. Fire Protection Associations (FPAs) will also be formed in South Africa in terms of the

National Veld and Forest Fire Act.

Fire prevention efforts need to be strengthened in Africa. A number of methods should be employed, including more effective signs, special warning messages in the media during dangerous periods, school programmes and community outreach programmes. It is also important for an effective programme in South Africa to consider the social context of the fire programme (Calvin & Wettlaufer, 2000).

9.3.3 Delivering Fire Prevention Messages

Fires started by people are responsible for the majority of damaging fires in Africa. These fires threaten the wealth and livelihood of local communities and threaten ecosystems and endangered wildlife. Most people are unaware of these impacts. Prevention of these fires requires the public's understanding of the damaging aspects of fire and actions that lead to their elimination or reduction.

9.3.3.1 Determining the Fire Prevention Message

A fire prevention message stresses two points. The first is to convey how fire can affect communal wealth and environment. The second stresses actions communities and individuals must take to reduce the risk of destructive fires. Developing fire prevention messages requires thoughtful consideration of the following factors:

- What are the real as well as the potential fire problems?
- What are the causes of the problems?
- What are the solutions?
- What actions can communities, companies and individuals take?
- Who is the target group?
- What are the social and cultural barriers to fire prevention?

Example messages:

- Problem: Fires are destroying significant portions of the country's pine plantations. Message: "Don't let jobs go up in smoke!"
- Problem: Honey-hunter fires are the major cause of fires in the Chui Mountain region. Message: "Fire left behind in the forest leads to destruction!"
- Problem: The fire danger is extreme with high winds expected. Message: "Open fires and burning are not permitted for two days."

Messages must be simple and clear. Ambiguous messages can be confusing and ineffective.

9.3.3.2 Delivery Methods

A combination of visual, verbal and written methods can be used to deliver fire prevention messages. Selection of the correct method is important if the messages are to reach their intended target group. For areas where literacy is low, messages that employ visual elements and cues can be very effective. Care should be taken where culture and tradition toward fire is counter to fire prevention. The delivery of fire prevention messages can be organised in the form of a campaign. Campaigns allow the fire prevention message to be delivered in a variety of methods under a single banner or slogan. They are an

excellent way to increase public awareness and to gain support.

Typical delivery methods include:

- *Fire prevention symbols*

Using a symbol similar to “Smokey Bear” (the well-known US symbol) can be a powerful way to communicate the fire prevention message. Many countries have used a caricature of an indigenous animal to give guidance in the proper way to use fire. An animal symbol can be very successful with children. Other types of symbols that depict the consequences of fire can be used for adults.

- *Schools*

Fire prevention training in schools is very important, since establishing proper attitudes towards fire begins at a young age. Parents are also reached as children take the messages home. Fire personnel can visit schools and teach fire safety. In addition, a fire prevention curricula and materials for teachers can be developed. In both cases, it is important to foster co operation with local educators.

- *Mass media*

Radio, television, newspapers and other publications provide one of the best means for delivering the fire prevention message. They also can be used to warn the public of dangerous fire weather conditions. Reports of damage from recent or ongoing fires provide a powerful way to stress fire prevention. Caution should be taken not to rely on mass

media to reach all of the target audience in areas where access to radio and television is limited.

- *Associations, groups and corporations*

Fire prevention efforts can be greatly extended by enlisting the aid and co operation of groups and associations. Examples of these groups are:

- Scouting organisations
- Wildlife clubs
- Environmental groups
- Home-owner associations
- Motoring associations

Corporations can also be enlisted to provide assistance and sponsorship, especially if they are impacted by fire. Examples of corporations include:

- Insurance companies
- Wood product companies
- Safari and tour companies
- Agricultural companies

- *Posters, signs and other means*

Posters and signs can be used to deliver a variety of fire prevention messages and can contain a combination of textual and visual elements. Signs usually convey instructions to the public. Use of signs can warn the public of high fire danger and can provide specific instructions on the use of fire. Placement of signs is a critical consideration. If they are placed along roadways, signs must be visible to passing traffic and sized to be legible at the normal speed of passing traffic. Signs related

to specific conditions, such as high fire danger, should be removed as soon as the condition no longer exists.

Fire prevention posters are intended to deliver fire prevention messages, usually in an eye-catching and straightforward way. Posters can be used wherever people gather, such as bus stations, markets, public buildings and schools.

Other aids to fire prevention delivery include balloons, pencils, stickers, etc., imprinted with the fire prevention symbol and messages.

- *Public figures*

People who are well-known and respected can be enlisted to deliver the fire prevention message. Examples include sports figures, entertainers (films, television, radio, music), and other public figures. Consider a fire prevention day at a football game, for example, where prevention material is distributed or members of the team talk to the crowd about fire prevention. This might also extend down to the local level where village elders instruct people about the wise use of fire.

9.3.3.3 Evaluation

In order to judge the effectiveness of fire prevention messages, periodic evaluations should be conducted. An evaluation might be manifested in a reduction of fires, but this often can be misleading over a short period of time due to other factors such as wet and dry weather patterns. Conducting a sample survey among the targeted



9.9



9.10

group about their attitudes toward fire prevention, how they have changed their behaviour, and what benefits they have perceived will indicate if the messages are being received.

9.4 SOME NOTES ON FIRE DANGER

Figure 9.9. Multi-lingual sign (Photo: M.F. Calvin).

Figure 9.10. Fire prevention poster (Photo: J. Jones).

RATING

During 1998, South Africa passed a new National Veld and Forest Fire Act (Act No. 101 of 1998). The Act provides for the prevention of veld fires through the deployment of a National Fire Danger Rating System (NFDRS). Such a system does not exist at a national level at this stage, although localised fire danger rating systems are used in some regions such as the KwaZulu-Natal Midlands and Mpumalanga. In response to this requirement, a study is currently under way to develop a National Fire Danger Rating System for South Africa. A team of experts – in consultation with the Fire Committee of the Department of Water Affairs and Forestry – have outlined the criteria that need to be considered for a suitable NFDRS for South Africa (Willis et al., 2001).

Since South Africa has a wide range of climatic conditions and vegetation types, the country has been divided into nine zones that are sufficiently homogenous to allow for a single meaningful fire danger rating per region. Municipal boundaries were also taken into account to facilitate management, administration and communication of these zones. The nine zones are:

1. Lowveld and Eastern Interior
2. East Coast to Escarpment
3. Southeast Coast to Escarpment
4. Southern Coast
5. South-Western Cape
6. Western Interior
7. Northern Interior
8. Central Interior
9. Kalahari

A number of fire danger rating systems that are

used nationally and internationally were examined and their suitability to South African conditions were determined. Factors that were taken into account included:

- The diversity of South African users (rural subsistence farmers to urban dwellers).
- The diversity of languages.
- The diversity of literacy levels.
- Geographical spread.
- The diversity of population communication abilities.
- Available infrastructure.

On the basis of these criteria, four models (the Canadian Forest Fire Danger Rating System, the United States Fire Danger Rating System and the McArthur Grassland and Forest Fire Danger indices) have been selected as potential systems for South Africa. Willis et al. (2001) recommend that the performance of the four models should be tested over a full range of fuel and climatic conditions in South Africa for one year.

Communication of fire danger rating indices to the public is essential if the NFDRS is to be effective. Willis et al. (2001) present a colour-coded system for depicting fire danger that would be suitable for South Africa. The system has five colour-coded fire danger rating categories. Each of these has the expected fire behaviour, recommended control measures, actions and restrictions for each category. The ratings will need further refinement before being incorporated into the final NFDRS. Willis et al. (2001) recommend that the South African Weather Bureau should communicate fire danger rating indices and fore-

casts to the Fire Protection Associations and the public. The Fire Protection Associations will have the responsibility of co-ordinating activities relating to the prevention and combating of fires in their areas of jurisdiction.

In order to adapt and improve the model to South African conditions, Willis et al. (2001) make a number of recommendations. These include analysing historic weather data to provide an understanding of the range of the index for the different seasons and fire conditions experienced within each region. The implementation of this National Fire Danger Rating System – together with appropriate law enforcement – will enable the prediction of potentially hazardous fires and enable effective preventative measures to be taken.

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10

FIRE DETECTION AND CONTROL

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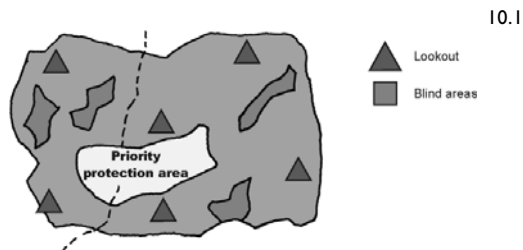
10.1 FIRE DETECTION

10.1.1 Fire Lookout Systems

Lookouts are a well-proven method of fire detection and can be an important part of an overall fire protection system. They can be permanent or temporary, staffed or automated. Lookouts are typically located on high points such as hilltops, where visibility is good. Visibility is often improved by building lookout towers where natural elevated points do not provide adequate height.

10.1.1.1 Planning a Lookout Network

The purpose of a lookout is to ensure the early discovery of fires. Early discovery reduces the time it takes for fire attack, resulting in smaller fires and lower costs. Planning a lookout network or evaluating an existing network is important to ensure that it is effective and in harmony with overall fire protection goals and budgets.



Lookouts can range from sending a person with a radio to a hilltop during times of high fire danger, to a constructed tower that is staffed full-time, or to an infrared automated tower with communication links to headquarters. In any case, there are key items to consider when planning a lookout network:

- **Coverage Area**

Determine the overall region that needs to be covered by lookouts. This is usually based

Figure 10.1. Fire lookout network (M.F. Calvin).

on a fire management plan that identifies protection priorities and areas of high risk and value.

- *Visible area*

Natural features such as mountains, ridgelines and vegetation can block what is seen from the lookout. Placement should maximise the total area seen among all the lookouts in the network and reduce the blind areas. This can be done recording and overlaying seen areas from each lookout on a map. Most Geographical Information Systems (GIS) can perform this task.

- *Visibility quality*

Consider any impediments to visibility, such as haze from urban areas, mist and smoke. In many areas of Africa, haze from fires during the dry season can severely reduce visibility during times when early detection is important. Normal range of visibility is from 30–40 km. Reduced visibility may require additional lookouts.

- *Communications*

The ability to communicate smoke reports quickly is absolutely vital; a good lookout system depends on it. Radio and telephones provide the most effective means. If these are not available, use a messenger to convey the smoke report to headquarters.

- *Facilities and technology*

Determine the type of lookout to be used. Evaluate staffing, construction, maintenance and technology costs. Minimum tool requirements for staffed lookouts include binoculars, maps and communications.



10.1.1.2 Staffed Lookouts

- *Duties of a lookout*

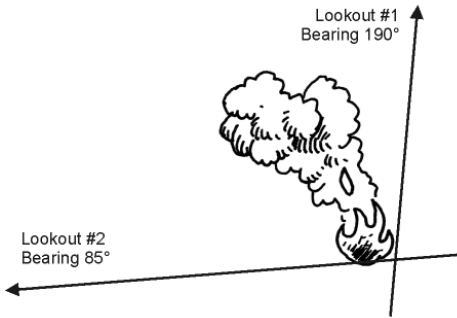
Lookouts are the eyes on the ground of the fire protection organisation. Reporting fires in a rapid and accurate manner is essential to quick suppression. In order to qualify as lookout, one must have good eyesight, be trustworthy, be able to read maps and use the tools of the job (compass, radio, etc.). The first job of a lookout is to learn the country that can be seen from the tower. This is achieved by locating prominent landmarks, such as mountains, rivers, buildings and roads, using a map of the area and a compass. Also to locate sources of dust such as roads and smoke from sawmills, buildings, etc., in order to avoid false alarms and to locate and mark these sites on the lookout map. Areas that have a higher risk of fire, such as logging operations, campgrounds, and villages, must also be marked on the map, and people who are familiar with the area must be used to advantage.

- *Detecting smoke*

Looking for smoke and a potential fire is the primary job of the lookout. A systematic approach should be used to scan the area for smoke. At 15-minute intervals (dependent

Figure 10.2. Scanning sectors (M.F. Calvin).

10.3



on the fire danger), the entire seen area should be scanned. First, divide the area into sectors of approximately 45° . Use ridges, rivers, or other features to form the sector's boundary. Scan each sector by starting closest to the lookout, and then work to the limit areas visible. Proceed in a clockwise manner until all sectors have been covered. Binoculars are essential to thoroughly examine the entire visible area.

- *Identifying smoke*

Once smoke has been detected, the lookout must rapidly determine if it represents a fire and take action to report it to headquarters. Smoke can be classified as legitimate, false and illegitimate. Legitimate smoke, is authorised by permit or are emitted by industrial plants, homes, etc. False smoke is something that could be mistaken for smoke, such as mist and dust. Illegitimate smoke is smoke that does not fall into the first two categories and must be reported to headquarters. Smoke where the source is in doubt should be reported.

- *Determining the fire's location*

In order to dispatch personnel, the fire's location must be accurately determined. This

can be done in a number of ways depending on the equipment available. First choice is to use a fire-finder, if available. A fire-finder is a sighting device mounted in the lookout building that combines a map and the features of a compass. The fire-finder provides a very accurate way to determine the fire's bearing in degrees and distance from the lookout.

A map and compass are a good alternative to a fire-finder. The compass is used to determine the fire's bearing in degrees from the lookout, and then estimate the distance from the lookout by plotting the bearing on the map and measuring the distance along the plotted line to the smoke's location. If two or more lookouts can see the smoke, their bearings can be plotted on a map, in a method called triangulation, which increases accuracy. Without the above tools, use geographic landmarks to provide a reference to the fire's location by estimating the distance and direction from the landmark.

- *Reporting the fire*

Once the location of the smoke has been determined it should be promptly reported to headquarters. Minimum information to report includes:

- The location of the fire using geographic references and landmarks (e.g. 2 km north of Kwai village).
- The bearing in degrees and the distance from the lookout (e.g. 255° by 12 km).
- What is burning (e.g. grass and trees).
- Smoke description, including volume, colour and drift direction (e.g. thin column of smoke, dark grey, drifting to east).

Figure 10.3. Determining location by triangulation (M.F. Calvin).

- Fire description, if visible, including size, direction of spread, and fire behaviour (e.g. two hectares, spreading to the east at a rapid rate).
- Date and time of first observation.

10.1.1.3 Automated Lookouts

Automated lookouts have been in use in various countries around the world for decades. Technology has evolved to include various types of detection mechanisms, including high-resolution digital cameras and infrared sensors. These cameras can be controlled from a central location or they can be set to scan the visible area under computer control. Some systems use sophisticated image processing that can discern smoke without human involvement, trigger an alarm and provide very accurate location information. In addition, this type of system has the ability to be integrated with other command and control information and GIS systems, increasing its effectiveness. These systems have many advantages over conventional staffed lookouts, but they are expensive and require other infrastructure, such as communication links and computers. Automated lookouts are probably not a realistic detection alternative in Africa, except in areas where the value of protected areas is very high and the infrastructure exists to support them. Some are in operation in certain forestry regions of South Africa, e.g. the FIRE HAWK system (Zululand Fire Protection Services, 2004). For details on the advanced system see Kührt et al. (2000) and a special issue of *International Forest Fire News* (IFFN, 2000).

10.1.2 Ground Patrolling

To deal effectively with a fire, a fire manager must firstly know it exists. There are many methods of detecting fires rapidly, from mountain-top infrared scanners, cameras and lookout towers to people patrolling the forest. All detection methods are designed to determine a fire exists as quickly as possible.

The Forestry Instructions of the South African Department of Forestry, No. 66 of 1979, mentions the use of patrolling as:

All areas, where fires occur regularly, and areas not covered by lookout towers, must be patrolled during high fire risk periods. Forest guards must have radios for effective communication.

The primary advantage of the ground patrol method is its flexibility. Where terrain prevents lookout points, foot and bicycle patrols connected to firefighting teams can be organised during the fire season. Patrol routes must be planned to cover hazard and danger areas, taking into consideration high-risk areas such as flammable vegetation, wild bees and human activities. Patrols must be in constant communication with ground crews so as to dispatch support as quick as possible.

In areas where severe fire danger periods occur for a limited period, certain special actions can be implemented, for example the use of highly trained firefighting teams that are contracted by forestry companies, which are placed at strategic sites on days with a high fire danger index. Over and above these actions, foresters and other line managers may also patrol their plantations and high-danger areas by car.

In the Zululand coastal areas, ground patrolling is not very effective, as they have to contend with a relatively flat terrain. Lookouts, together with electronic fire detection cameras, on the other hand, pick up signs of smoke fairly quickly due to long-distance visibility. On high danger days, the fire duty team is put on standby, together with their relevant fire tenders in strategic areas. Each plantation has worked out where the most central (or accessible area) is, and this is used to position standby crews and equipment. They are then mobilised at any hint of fire.

However, in some areas an important contribution is made by ground patrols that can improve local information. This information is then coupled with detailed plantation maps, covering every foot-path, changes in vegetation, flowering and fruiting seasons of main species, and any detail that will have relevance during a fire in the area.

10.2 FIRE PREPAREDNESS, DISPATCHING AND COOPERATIVE SCHEMES

In order to be successful, fire protection organisations must maintain a state of readiness where forces can be deployed to reported fires rapidly and, once at the fire, organise and direct in an effective manner.

10.2.1 Provisioning and Preparing Firefighting Resources

Preparedness is the act of organising resources, in order to respond to a fire. Fire organisations require an adequate supply of firefighting resources that are available and ready to respond. Ensuring that the supply of resources meets the firefighting workload of the area under your control

is a very important responsibility. Judging the appropriate level of resource availability requires that you review the history of previous fires and analyse the types of resources used, and their effectiveness. One also needs to analyse alternative resource types to determine if they might increase capability. This analysis must take into account the resource usage cost and the values at risk from fire (see section on fire planning). Most organisations cannot afford the cost of a full-time firefighting force. Instead, a tiered approach is used to enable the call-up of additional resources if the situation dictates. A typical tiered approach is composed of the following:

- *Initial attack and other dedicated fire resources*
These forces are the most capable and highly trained available. Their state of readiness is usually the highest and they are expected to respond quickly (usually in minutes) when dispatched. They are normally paid out of fire protection budgets.
- *Reserve resources*
These forces are drawn from within the organisation or from other organisations as required, but are not normally assigned to fire duty. Personnel are usually identified before the fire season to fill specific roles based on their training and experience. Equipment used for non-fire tasks that could fill a fire role should be identified, and provisions made for its call-up, if needed. Reserve forces may be put on a higher state of readiness due to high fire danger or ongoing fires.

- *Emergency forces*

Often countries have provisions to acquire people or equipment on the spot, or to use volunteers. These forces may not have training and are often not equipped for firefighting, resulting in an unsafe situation if they are employed in actual fire line work. It is advisable to use these personnel in support jobs or for mop up, where they are not exposed to hazardous situations. Potential sources of emergency resources are:

- Local and national governmental departments and branches
- Military and civil defence
- Private ranches and farms
- Villages and towns

- *Local leader programme*

In Africa, another type of firefighting force is highly desirable due to scarce resources and long travel times. The local leader programme selects people from villages and towns to organise and direct firefighting operations. Each local leader should be able to bring people together to work on fires in their areas. The local department head, or their representative, should work with the local leader when a fire starts, or the local leader could attack the forest fire if they have had training and experience. Local leaders can have other responsibilities in addition to fire suppression. Local leaders may be used to locate and report fires, and to work with local people in the community in fire prevention. Local leaders can also instruct people in the area on how to use fire safely.

It is desirable to work out the protocols for requesting personnel and equipment before a fire starts. In some cases, a written agreement may be required.

The capability to provide logistical support to a fire is also very important. People require water, food and a place to rest. In addition, equipment requires fuel and lubricants. It is wise to acquire sufficient stocks before a fire and keep them in reserve. In addition, sources for emergency supplies should be identified, and payment procedures set up. It is important to identify medical facilities and develop evacuation procedures in case of an accident.

Firefighting forces should adhere to a standard of alertness that is appropriate to the level of fire danger. Each organisation should set its own standards for readiness and response. The following example is a standard for an initial attack hand crew during extreme fire danger:

- Remain in constant contact with the dispatch centre.
- Transportation is available, fully serviced and is located with the crew.
- Tools are sharp, in good repair and stored on the transport.
- Personal protective equipment is worn or available on the transport.
- Crew members are briefed daily on expected weather and fire conditions.
- Crew must respond to the fire within two minutes of the alarm.

During fire season, procedures should be implemented to facilitate notification of personnel and

to ensure staff are at the proper state of readiness. A number of lists should be maintained to indicate where fire personnel are located, if they are available for dispatch, and how they can be contacted. A duty officer should always be available to make decisions concerning fire-related matters. This responsibility can be shared among staff members. In addition, all staff needs to be kept informed of the current and forecasted fire conditions and advised of what actions they are to take. An area fire-preparedness plan that spells out all details of organisational and personal actions and responsibilities should be developed before fire season begins. Personal readiness is also very important. If you know that you are on a call-up roster of personnel who will work at a fire, there are steps you should take before you receive a fire assignment. Often you will not know which position on a fire you will fill, but preparing a “Fire Kit” in advance will help ensure that you have everything that you need and will reduce the amount of time between deployment and arrival at the fire. A typical “Fire Kit” contains:

- Agency/department ID badge.
- Pens, pencils, markers (both thin- and thick-point) and paper.
- Forms (e.g. accident and/or injury forms, inventory forms, etc.) that you will need.
- The appropriate functional annex to your organisation's fire plan.
- Other policies, procedures and instructions that you will (or might) need at the incident.
- Area maps.
- Masking tape and/or pushpins.
- A clipboard.

In addition, personal items should include:

- One or more changes of clothing (including shoes), especially if you could be deployed for some period of time.
- Toiletries and hygiene supplies.
- Outerwear, as appropriate to the incident, the season and the climate.
- A torch.
- Medications (both prescription and over-the-counter).

10.2.2 Pre-Attack Planning

Determining which fires to suppress is very important. Not all fires are equal in terms of potential damage. In fact, many fires are beneficial to the ecosystem.

Because firefighting resources are scarce, the decision to commit resources to a fire is a critical one. Placing limited resources on a low-threat fire might leave more valuable areas without adequate protection. To avoid this, fire management organisations should determine the protection levels for the areas within its boundaries. This will enable the dispatcher and responders to make informed decisions about the level of response required. Ideally, protection levels should be based on management objectives for the area (see section on Fire Planning in Chapter 9). For example, an area designated as a town's watershed might have a higher standard of protection than an Acacia Woodland savanna that is being used for livestock forage.

Although most areas in Africa do not have formal land management plans, protection levels can still be set by involving local officials and land

owners. Maps that identify protection areas should be developed. For each area, the maps should indicate:

- *Protection levels*
 - Critical: highest degree of fire protection.
 - Full protection: fire suppression where practical.
 - Limited protection: area burned limited to a specified size or to a predetermined boundary.
- *Values at risk*
 - Villages, tourism facilities, timber, forage.
- *Fuel types*
 - Species composition and structure.
- *Sources of water*
 - Wells, ponds, rivers, etc.
- *Access roads and trails*
 - Main roads, 4x4 trails, etc.
- *Action to take and notifications.*

Once protection areas have been established, response guidelines can be developed. Usually these response guidelines are divided into four levels, based on the fire danger or predicted rates of spread, when the fire occurs. These response guidelines can be designated green, yellow, orange and red, with each level specifying the type and quantity of resources to be dispatched, based on the fire danger.

Area response cards can be an effective way of documenting the above information, in a way that can be quickly accessed and used by dispatchers and responders. Table 10.1 provides an example of a dispatch response card.

10.2.3 Dispatching

Dispatching is at the centre of firefighting operations. Dispatch centres (also known as control, alarm or communication centres) can be compared to the body's central nervous system. They receive a report of a fire and provide a response in the form of mobilised resources and other actions. Dispatch centres may be small, such as a field office staffed by a single person, or they may large and complex, providing services for many different public safety functions, including fire, police and ambulance. They all perform the following functions:

- Keeping track of the location and availability of resources.
- Receiving reports of fire.
- Determining the appropriate response.
- Dispatching resources to the fire.
- Receiving orders and filling orders for firefighting resources.

The dispatcher is usually the Incident Commander until the first person arrives at the fire, since they make the initial assessment of the fire's behaviour and potential, and decide on the appropriate level of response. Often the decision is made in consultation with the responsible area fire manager.

Keeping abreast of the status of fire resources is one of the most important dispatching tasks. The dispatch centre should keep track of changes in the availability and location of all primary fire resources. At a minimum, any such changes should be reported daily by all fire personnel. Should radio communication be available, the reporting

Table 10.1. Example of area response card.

AREA RESPONSE CARD				
Area: 11b				
Upper Green River Valley	Protection Level: Full protection			
Size: 5000 ha.	Control Objective: Keep fires under ½ hectare in size.			
Fuel Type: Mountain Fynbos 80% (30 years old) with forest patches 20% in canyon bottom. Eastern boundary interfaces with a cluster pine plantation planted in 1994.				
Values at Risk:				
– Area is a watershed for the town of Sugarbush. – Plantation on eastern boundary. – Wamba Village on the southern boundary.				
Access: River road is accessible by all vehicles. Most of the area is not accessible by vehicle.				
Water: Water is easily obtainable along River Road.				
Resource	<i>Response Condition and resource quantity</i>			
	Green	Yellow	Orange	Red
Forestry Hand Crews (10 persons)	1	1	2	3
Pumpers (300 litre)	1	1	2	
Wamba Village Crews (10 persons)			2	3
Sugarbush Helicopter				1
Notes: 1. The Bundu Paper Company should be notified of all fires to the east of River Road. 2. Caution when using helicopters due to power lines along River Road. 3. Call Wamba police if fire is a threat to village.				

frequency should be increased depending on the situation.

When a report of a fire is received, either as a first-hand account or from a third party, the dispatcher must be prepared to acquire sufficient information in order to provide a correct response. A dispatcher should always obtain the following information when a fire is reported:

- Person reporting the fire as well as contact information – “Joseph Mzuri from Wamba, Telephone 510-1020”
- Exact location of the fire – “2 km east of the Mkubwa River bridge”
- Best access to the fire – “Road M140”
- Landowner – “Unknown”
- Size of the fire – “One hectare”
- Rate of spread and wind – “Creeping around on the ground. Moderate wind from the south”
- Suspected cause – “Campers”
- Values threatened – “Homes and bomas next to river”

After the fire report is received, the dispatcher or responsible official must determine an appropriate response to the fire. This decision is usually based on the following factors:

- *Values at risk*
Consideration should be given to potential threat to human life and damage to valued natural resources (timber, watersheds, forage, etc.), livestock and wildlife, and human-related values (structures, villages, facilities, etc.).

- *Fire potential*

The fire's reported and anticipated behaviour should be weighed. Both current and predicted weather conditions should be considered, as changes in wind speed and direction are critical. In addition, the type of vegetation involved, its flammability/dryness, and fuel load (light, medium or heavy) should be considered. Changes in vegetation based on the fire's direction of spread are also important. Lastly, the topography should be considered. The position of the fire's origin is significant. Fires starting on lower slopes have the potential to spread faster and burn a larger area than those starting higher up or on a flat terrain. Since this evaluation must be made without actually seeing the fire, the dispatcher must rely on personal knowledge of the area, and behaviour of past fires in the vicinity.

- *Resource availability*

The probability of control is related to the fire's behaviour and the resources applied to control it. This is directly affected by the amount and type of resources available and the time it takes for them to arrive at the fire. Additional resources may be added to the initial attack if it is judged that the initial attack force is not adequate. Travelling time is also a critical factor, as the longer a fire burns, the larger it becomes, and the more difficult it is to control.

The next step is to contact the initial attack forces and dispatch them. The fastest possible communication method should be used:

- Radio
- Telephone (landline, cell or satellite)
- Fire sirens and alarms
- Loud bells or drums
- Messengers (vehicle, moped, foot, etc.)
- Flags and air balloons

During periods of high fire danger, forces must be in a position to receive assignments promptly. The ability to communicate with firefighting forces is vital. Good communications result in smaller fires since the elapsed time from when the fire is reported to the first arrival of crews on the fire is reduced. Good communications also enable the Incident Commander to provide updates to headquarters and request additional resources in an expedient manner. In addition to communication with crews on the fire, the dispatch centre needs communication channels to other organisations that may be sources of additional resources. Dispatch centres perform other duties, including:

- Obtaining and communicating weather forecasts and fire danger ratings.
- Keeping apprised of fires and conditions on adjoining jurisdictions.
- Maintaining logs of all actions and important events.
- Requesting forces and assistance from other organisations.
- Alerting other authorities, such as police and municipal services.

10.2.4 Receiving a Fire Assignment

In addition to being prepared for a fire, firefighting forces should go through a series of steps when they receive a dispatch order, to ensure they

understand their assignment and the location and time they are to report. Some of the questions that need to be answered by the crew leader, or individual receiving the order, are:

- When should you report and where?
- What is your assignment?
- To whom will you report (by name and position, if possible)?
- Approximately how long should you plan to be deployed?
- What is your role? Do you have decision-making authority? Are you a supervisor? If so, how many people will you supervise?
- What procedures are in place for contacting your day-to-day supervisor?
- How can your family reach you if they have an emergency?
- You may not be able to obtain all of this information at the time you are activated, but you should gather as much information as you can.

10.2.5 Cooperative Firefighting Schemes

Many fire organisations have discovered the advantages of cooperating with each other and with organisations that have a compatible mission. The fact is, few organisations have the personnel or equipment to handle every fire situation. Co-operation offers many benefits such as:

- Expanded firefighting capacity by sharing resources.
- Faster initial attack by using the closest available forces.
- Extended budgets by combining operations and sharing facilities where feasible.

- Increased organisational knowledge by sharing information and expertise.
- Improved fire training by sharing instructors and facilities.

The following schemes have been found to be effective in increasing cooperation:

- *Fire cooperatives*

Fire cooperatives (also known as Fire Coordination Groups or Fire Protection Associations) are an excellent way to facilitate cooperation. The cooperative is composed of representatives of organisations involved in firefighting operations, landowners and emergency services within a geographical area. This area could be local, regional, national or even international. Cooperatives work to solve common problems and increase cooperation. In some countries, cooperatives are encouraged through enabling laws and policies. Fire cooperatives often form sub-groups to work on specific issues like fire prevention and training.

- *Cooperative agreements*

Cooperative agreements offer a mechanism for formalising cooperation between organisations. These agreements may address specific elements of cooperation, such as sharing of personnel and equipment and how reimbursement will be handled, or they may form a broad framework under which other agreements may be developed. Agreements are official documents, which must be written within the laws of the country and signed by authorised officials.

- *Closest forces concept and resource sharing*

The “closest forces concept” is used to dispatch firefighting resources nearest the fire, regardless of their organisation and the jurisdiction where the fire is located. For example, a fire has been reported near the boundary of organisation A. Organisation B has a crew that is 10 minutes away, while organisation A’s closest crew is 30 minutes away. In this case, using the closest forces concept, organisation B’s crew is sent to the fire.

Resource sharing is a principle where organisations agree to share personnel and equipment. This sharing is usually centred around fire suppression, but it can include other areas, such as training.

- *Reciprocal protection*

Often organisations have areas that can be better protected by another organisation. This may be due to distance, access or other reasons. In this case, the protection of these areas can be swapped so that the total fire suppression workload can be optimised. This does not mean changing the administration of these lands, only the fire protection. This type of scheme requires a formal agreement between the participating organisations.

Finally, in many areas of Africa, fires starting in one country cross an international boundary into another country. Often these fires are large and by the time they cross, are too large for the impacted country to handle. Many countries in other parts of the world have found that these cross-boundary issues can be addressed and overall cooperation improved by using the above schemes.

10.3 INCIDENT COMMAND SYSTEM

The Incident Command System (ICS) is recognised as an effective system for managing fires and other emergencies. ICS was developed in the United States during the 1970s in response to a series of major wildland fires in southern California. At that time, municipal, county, state and federal fire authorities collaborated to form the Firefighting Resources of California Organised for Potential Emergencies (FIRESCOPE). FIRESCOPE identified several recurring problems involving multi-agency responses, such as:

- Non-standard terminology among responding agencies.
- Lack of capability to expand and contract as required by the situation.
- Non-standard as well as non-integrated communications.
- Lack of consolidated action plans.
- Lack of designated facilities.

Efforts to address these difficulties resulted in the development of the ICS. Although originally developed in response to wildfires, ICS has evolved into an all-risk system that is appropriate for all types of fire and non-fire emergencies. Much of the success of ICS has resulted directly from applying:

- A common organisational structure.
- Key management principles in a standardised way.

Since its inception, ICS has been recognised as the international model for managing emergency

situations. It has been used in countries throughout the world. In 2000, ICS was used in Ethiopia to help manage a siege of major fires.

ICS is based on the premise that no single agency or department can handle every fire situation alone. Everyone must work together to manage the emergency. To coordinate the effective use of all of the available resources, agencies need a formalised management structure that lends consistency, fosters efficiency, and provides direction during a response.

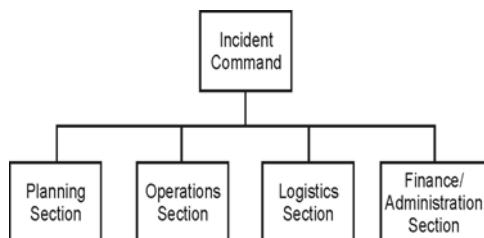
The ICS organisation is built around five major components:

1. Command
2. Planning
3. Operations
4. Logistics
5. Finance/administration

The relationship among these components is shown in Figure 10.4.

A key feature of ICS is its scalability. ICS is designed to be used on small fires requiring just a few people, but is also adaptable to fires of great complexity requiring thousands of personnel. On small-scale incidents, all components may be managed by one person, namely by the Incident Commander. Large-scale incidents usually require that each component or section be set up separately. Additionally, each of the primary ICS sections may be divided into smaller functions as needed. The ICS organisation has the capability to expand or contract to meet the needs of the incident, but all incidents – regardless of size or

10.4



complexity – will have an Incident Commander. A basic ICS operating guideline is that the Incident Commander is responsible for on-scene management until command authority is transferred to another person, who then becomes the Incident Commander.

10.3.1 The Command Function

The command function is directed by the Incident Commander, who is the person in charge at the incident and who must be fully qualified to manage the response. Major responsibilities for the Incident Commander include:

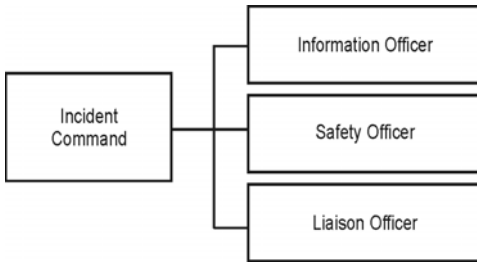
- Establishing command and setting up the command post.
- Protecting life and property.
- Controlling personnel and equipment resources.
- Maintaining accountability for responder and public safety, as well as for task accomplishment.
- Establishing and maintaining an effective liaison with outside agencies and organisations.
- Ensuring personnel safety.
- Assessing incident priorities.
- Determining operational objectives.
- Developing and implementing the Incident Action Plan (IAP).
- Developing an appropriate organisational structure.
- Maintaining a manageable span of control.
- Coordinating overall emergency activities.
- Authorising the release of information to the media.
- Keeping track of costs.

An effective Incident Commander must be assertive, decisive, objective, calm and a quick thinker. To handle all of the responsibilities of this role, the Incident Commander also needs to be adaptable, flexible and realistic about his or her limitations, and must have the capability to delegate positions appropriately as needed for an incident. The Incident Commander will normally be the first senior responder to arrive at the fire. As additional responders arrive, command will transfer on the basis of who has primary authority for overall control of the incident. As incidents grow in size, or become more complex, the responsible jurisdiction may assign a better qualified Incident Commander. At transfer of command, the outgoing Incident Commander must give the incoming Incident Commander a full briefing and notify all staff of the change in command.

As an incident grows, the Incident Commander may delegate authority for performing certain activities to others. When expansion is required, the Incident Commander will establish the other Command Staff positions shown in Figure 10.5, and draw up a list of staff positions as follows:

Figure 10.4 ICS components (M.F. Calvin).

10.5



- The Information Officer handles all media inquiries and coordinates the release of information.
- The Safety Officer monitors safety conditions and develops measures for ensuring the safety of all assigned personnel.
- The Liaison Officer is the on-scene contact for other agencies and departments assigned to the incident.

The Incident Commander will base the decision to expand (or contract) the ICS organisation on major incident priorities:

- *Safety*
The Incident Commander's first priority is always the safety of assigned personnel and the public.
- *Incident stability*
The Incident Commander is responsible for determining the strategy that will:
 - Minimise the effect that the incident may have on the surrounding area.
 - Maximise the response effort while using resources efficiently, in keeping with the complexity of the incident and not just the

size. As incidents become more involved, the Incident Commander can activate additional general staff sections (i.e. Planning, Operations, Logistics, and/or Finance/Administration) as necessary. Each Section Chief, in turn, has the required authority to expand internally to meet the needs of the situation.

10.3.2 The Planning Section

On smaller incidents, the Incident Commander is responsible for planning, but when the incident is of larger scale, the Incident Commander establishes the Planning Section. The Planning Section's function includes the collection, evaluation, dissemination and use of information about the development of the incident and status of resources. This section's responsibilities can also include creation of the Incident Action Plan (IAP), which defines the response activities and resource utilisation for a specified time period.

10.3.3 The Operations Section

The Operations Section is responsible for carrying out the activities described in the IAP. The Operations Section Chief co-ordinates Operations Section activities and has primary responsibility for receiving and implementing the IAP. The Operations Section Chief reports to the Incident Commander and determines the required resources and organisational structure within the Operations Section. The Operations Section Chief's main responsibilities are to:

- Direct and coordinate all operations, ensuring the safety of Operations Section personnel.

Figure 10.5. Command staff (M.F. Calvin).

- Assist the Incident Commander in developing response goals and objectives for the incident.
- Request (or release) resources through the Incident Commander.
- Keep the Incident Commander informed of both the situation and resource status within operations.

10.3.4 The Logistics Section

The Logistics Section is responsible for providing facilities, services and materials, including personnel to operate the requested equipment for the incident. This section takes on great importance in long-term operations. It is important to note that the Logistics Section functions are geared to support the incident responders.

10.3.5 The Finance/Administration Section

Though sometimes overlooked, the Finance/Administration Section is critical for tracking incident costs and reimbursement accounting. Unless costs and financial operations are carefully recorded and justified, reimbursement of costs is difficult, if not impossible. The Finance/Administration Section is especially important when the incident is of a magnitude that may result in a disaster declaration. Each of these functional areas can be expanded into additional organisational units with further delegation of authority. They also may be contracted as the incident de-escalates.

Note: ICS has over 60 types of positions and only a few of the basic and essential positions are covered here. To obtain additional information visit this website: www.nwcg.gov.

10.3.6 ICS Concepts and Principles

ICS is composed of major components to ensure quick and effective resource commitment and to minimise disruption to the normal operating policies and procedures of responding organisations. ICS concepts and principles have been tested and proven over time in business and industry and by response agencies at all governmental levels. ICS training is required to ensure that all who may become involved in an incident are familiar with ICS principles. An ICS structure should include:

- Common terminology
- A modular organisation
- Integrated communications
- Unity of command
- A unified command structure
- Consolidated IAPs
- A manageable span of control
- Designated incident facilities
- Comprehensive resource management

- *Common terminology*

Common terminology is essential in any emergency management system, especially when diverse organisations are involved in the incident. When organisations have slightly different meanings for terms, confusion and inefficiency can result. In ICS, major functions, facilities and units are designated and given titles. ICS terminology is standard and consistent. Other guidelines for establishing common terminology include:

- Response personnel should use common names for all personnel, equipment and facilities.

- Radio transmissions should use clear text (that is, without “ten” codes or agency-specific codes).

- *Modular organisation*

A modular organisation develops from the top-down organisational structure at any incident. “Top-down” means that, at the very least, the command function is established by the first arriving person who becomes the Incident Commander. As the incident warrants, the Incident Commander activates other functional areas (i.e. sections). In approximately 95% of all incidents, the organisational structure for operations consists of command and single resources (e.g. one fire truck, an ambulance or a tow truck).

- *Integrated communications*

Integrated communications use a common communications plan, standard operating procedures, clear text, common frequencies and common terminology.

- *Unity of command*

Unity of command is the concept by which each person within an organisation reports to only one designated person. A unified command allows all agencies with responsibility to manage an incident by establishing a common set of incident objectives and strategies. Unified command does not mean losing or giving up agency authority. The concept of unified command means that all involved organisations contribute to the command process by:

- Determining overall objectives.
- Planning jointly for operational activities while conducting integrated operations.
- Maximising the use of all assigned resources.

Under unified command, the following always apply:

- *Consolidated incident action plans*

Consolidated Incident Action Plans (IAP) describe goals, operational objectives and support activities. The decision to have a written IAP is made by the Incident Commander. ICS requires written plans whenever the incident is complex (e.g. if changes in shifts of personnel or equipment are required). IAP's should cover all objectives and support activities that are needed during the entire operational period. IAP's that include the measurable goals and objectives to be achieved are always prepared around a timeframe called an operational period. Operational periods can be of various lengths, but should be no longer than 24 hours; 12-hour operational periods are common for large-scale incidents. The Incident Commander determines the length of the operational period based on the complexity and size of the incident.

- *Manageable span of control*

A manageable span of control is defined as the number of individuals one supervisor can manage effectively. In ICS, the span of control for any supervisor may fall within a range of three to seven resources, with five being the

optimum. If resources increase or decrease beyond this range, the Incident Commander should re-examine the organisational structure.

- *Designated incident facilities*

Designated incident facilities include:

- An Incident Command Post (ICP) at which the Incident Commander, the Command Staff and the General Staff oversee all incident operations.
- Staging areas at which resources are kept while awaiting incident assignment.
- Other incident facilities may be designated for incidents that are geographically dispersed, require large numbers of resources, or highly specialised resources.

- *Comprehensive resource management*

Comprehensive resource management maximises resource use, provides accountability and ensures personnel safety. All resources are assigned to a status condition:

- *Assigned* resources are performing and committed to active functions.
- *Available* resources are ready for assignment.
- *Out-of-service* resources are not ready for assigned or available status.

Any changes in resource location and status, must be reported promptly to the Resource Unit by the person making the change.

- *Personnel accountability*

Personnel accountability is provided throughout all of ICS. All personnel must check in as

soon as they arrive at an incident. Resource units, assignment lists and unit logs are all ways for personnel to be accounted for. When personnel are no longer required for the response, they must check out so that they can be removed from the resource lists.

The ICS principles can (and should) be used for all types of incidents, both small and large. Because ICS can be used at virtually any type of incident, it is important that all responders use the ICS approach.

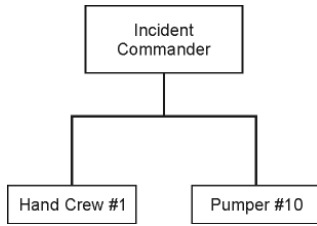
10.3.7 Expanding the ICS Organisation

The key attribute of ICS is that it is capable of handling both small and large incidents. ICS is expandable from small, routine operations into a larger organisation that is capable of responding to large incidents that cover many hectares or involve multiple communities or provinces. Most incidents will never require the activation of any of the four sections, but a few will require some or all of the sections to be established. This feature makes it an ideal organisational model for Africa. The following are three examples of how ICS can be applied:

Scenario #1 – A small grass and bush fire

At 14:00 a fire is reported near the river and a ten-person crew and pumper are dispatched by the communications centre (CC). Until the first person arrives at the fire, the CC director is the Incident Commander (IC). The pumper crew arrives at 14:15 and begins taking action. The fire is reported to be five hectares and spreading slowly toward the forest. At this point, the pumper crew leader becomes the IC. Ten minutes later the

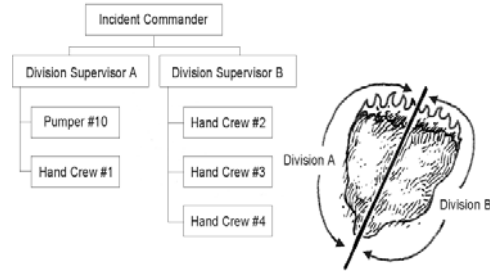
10.6



hand crew arrives. The hand crew leader, having more seniority and experience, assumes the IC position and reports this and the fire status to the CC. After 20 minutes the fire is brought under control. The decision is made to leave the pumper at the fire to patrol for another two hours. The pumper crew leader becomes IC again and the hand crew returns to their station. The pumper crew remains at the fire until it is declared “out” by the IC, and they then return to their station.

Scenario #2 – A medium-sized grass and bush fire
Using scenario #1 as a starting point. In this case the wind has picked up about ten minutes after the arrival of the hand crew and the fire is now spreading rapidly toward a plantation of pines. The IC (the hand crew leader) has assessed the situation and requested three additional hand crews. In order to manage a larger fire and reduce the span of control, the IC has divided the fire into divisions A and B. The IC determines the priority is on the left flank and assigns the pumper crew and hand crew #1 (now supervised by the assistant crew leader). The pumper crew leader is given the assignment of division A supervisor. The division supervisor is responsible for all fire suppression operations on division A. Note that

10.7



in this example the IC has elected not to institute the Operations Chief position. This means that the IC will assume responsibility for that position and direct overall operations on the fire. Twenty minutes later the area manager arrives from headquarters and assumes the position of IC. When the other crews arrive one of the leaders is assigned as division supervisor for division B. After three hours the fire is brought under control at about 30 hectares. One hour later all crews are released, except for the pumper crew and one hand crew. The IC position is turned over to the hand crew leader.

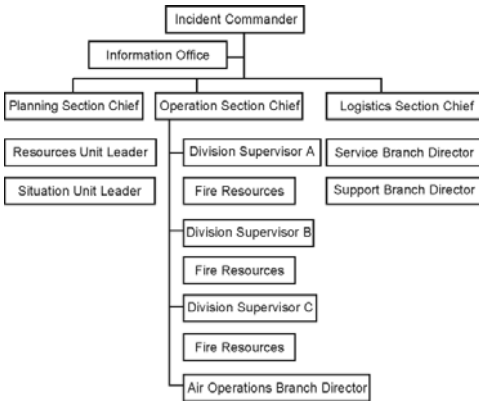
Scenario #3 – A large multi-day fire

This scenario displays a typical ICS organisation for a large and moderately complex fire. The fire has been burning for two days in 20-year old mountain fynbos and is about 450 ha. The terrain is steep and rocky. The weather forecast for the next two days is continued hot and dry. The fire is threatening a small town and a pine plantation. There are resources from multiple organisations on the fire, including 300 personnel and a number of pumps, water tenders, and bulldozers. In addition there are two military helicopters dropping water. The organisation for this fire is:

Figure 10.6. Scenario 1 organisation: A small grass and bush fire (M.F. Calvin).

Figure 10.7. Scenario 2 organisation: A medium-sized grass and bush fire (M.F. Calvin).

10.8



Rationale for the example #3 organisation

The size, complexity and number of personnel require a more robust organisation. Some of the key requirements for this fire are:

- **Increased logistical support.** Fires that last more than one day inherently require a larger logistics organisation in order to provide food, water and rest facilities for people, fuel and servicing for equipment, and firefighting tools and supplies. Providing these needs often consumes a great deal of effort. For this fire, three ICS positions are established to handle these needs:
 - A *Logistics Section Chief* is responsible for providing facilities, services and material support to the incident.
 - A *Service Branch Director* is responsible for providing services to the incident in the form of communications, food and medical aid.
 - A *Support Branch Director* is responsible for providing supplies (tools and other fire-

fighting equipment), facilities (camps, staging areas, etc.), and support to both vehicles and equipment (fuel, lubricants, and repairs).

- **Increased planning support.** A planning section is required to gather intelligence and prepare written plans. Information is needed to understand the current situation, to predict probable fire spread and to develop alternative control strategies. It is critical to have a comprehensive plan in order to coordinate resources, focus on incident priorities, determine incident needs and to predict a probable course of events. A written plan and documentation of actions are also needed to provide for possible legal action after the fire. For this fire, three ICS positions are added:
 - A *Planning Section Chief* is responsible for the overall collection, evaluation, dissemination and use of information about the development of the incident and status of its resources.
 - A *Resources Unit Leader* is responsible for tracking all the resources (people and equipment) assigned to the fire. This information includes their type (capability), status and location.
 - A *Situation Unit Leader* is responsible for collecting information about the fire. This includes preparing maps, forecasting its spread, obtaining weather forecasts and posting status information.
- **Aviation support.** An Air Operations Branch Director position is established in this case to

Figure 10.8. Scenario #3 organisation: a large multi-day fire (M.F. Calvin).

help coordinate the use of helicopters and to ensure their activities are in harmony with ground actions.

- **Public information dissemination.** This fire has generated a great deal of public interest. The Information Officer is responsible for providing public information in the form of press releases and media briefings.
- **Increased operational capability.** The Operation Section Chief position is established to handle the scope and complexity of this fire. Tactical operations pass from the IC to this position, allowing the IC to manage the broader aspects of the incident. This is in keeping with the ICS span of control principle.

10.3.8 Incident Action Plans

The Incident Commander is responsible for overseeing the development and implementation of an Incident Action Plan (IAP). For simple incidents, the IAP may be prepared by the Incident Commander and may not be written. In more complex incidents, the IAP will be a written document that is developed by the Planning Section under the direction of the Incident Commander. IAPs are always based on incident needs and the ICS organisation. They must be flexible and must be re-evaluated constantly. IAPs are developed for specified time periods. These time periods, called operational periods, are determined by the needs of the incident. In rapidly escalating or very complex incidents, the operational periods should be shorter to allow for rapid response to changing events. In smaller, less complex incidents, the

operational periods should be longer but usually do not exceed 12 hours.

ICS provides forms that can be used for assembling the IAP. However, the IAP can also be developed using the following structure:

- Incident summary includes:
 - Map of fire, including major geographical features, incident facilities and delineation of divisions.
 - Fire statistics, including size and resource damage.
 - Summary of current actions.
- Incident organisation chart with names of incumbents.
- Incident objectives include:
 - Control objectives and alternatives if required.
 - Weather and fire behaviour forecasts.
 - Safety message and warnings.
- Incident assignment includes:
 - A list of all major staff by positions, including those not shown on the organisation chart that may be needed for contact purposes (i.e. who do I call if I need drinking water?)
 - An assignment sheet for each division that contains a list of all the resources assigned and their leaders, the control objectives and tasks to perform.

10.3.9 Incident Facilities

There are three main facilities that the Incident Commander can establish based on the needs of the incident:

1. *Base*

The location at which primary logistics functions for an incident are coordinated and administered. There is only one Base per incident (incident name or other designator will be added to the term Base). The Incident Command Post may be co-located with the Base.

2. *Incident Command Post*

The location at which the primary command functions take place. The Incident Commander is located at the ICP.

3. *Staging Area*

Staging areas are locations where resources can be placed while awaiting a tactical assignment.

- Providing a more effective way to plan resources.
- Providing an effective way to request resources.
- Improving organisational expandability for large operations while maintaining a good span of control.

An important part of resource management is tracking resource availability. This is usually done by the leader of the resource, the division or unit it is assigned to. The information is communicated to the Incident Command Post. All operational resources at an incident will be in one of three status conditions:

- Assigned resources are performing active functions.
- Available resources are ready for immediate assignment.
- Out-of-service resources are not ready for assigned or available status.

10.3.10 Incident Resource Management

The effective management of operational resources is an important consideration at any incident. The ability to select the correct resource(s) for the task is essential to accomplishing the task, ensuring resource safety and ensuring the cost-effectiveness of the operation. Resource management also encompasses maintaining the status of all resources assigned to an incident.

Resources used in operations consist of all personnel and major items of equipment that are available, or potentially available, for assignment to incidents (equipment resources also include the personnel required to operate and maintain them).

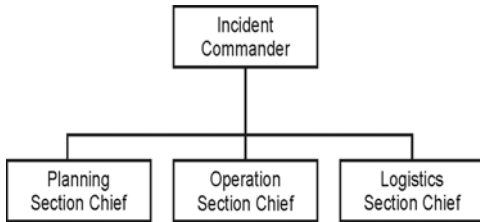
A combination of single resources assembled for a particular operational need, along with common communications and a leader is called a *Task Force*. Grouping single resources into Task Forces offers the Incident Commander several advantages for resource management, including:

10.3.11 Using the Incident Command System in Africa

ICS is a very flexible and adaptable organisational model. It can be modified to fit the situation as long as the basic principles are followed. This makes it ideal for use in Africa. For countries and organisations that do not have a lot of experience organising for a large or multi-day fire, a minimum suggested organisation consists of the following (see Figure 10.9).

This will provide a simple upper-level framework that will help staff manage the fire in a team setting with clearly defined roles. Of critical importance is the establishment of a planning

10.9



process under the direction of the Planning Section Chief. He or she must conduct a minimum of one planning meeting a day with the IC and the other section chiefs. When implementing ICS, consideration should be given to:

- Standard organisational chain of command and structure.
- Work place customs and protocol.
- Cultural differences with the principles of ICS.

In addition, the following will greatly facilitate ICS implementation:

- Acquire someone who has ICS experience to act as an advisor.
- Find the people in the organisation that know how to make things work and bring them into the ICS organisation.

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Figure 10.9. Minimum Organisation.

11

VELD AND FOREST FIRE EQUIPMENT

Deon Brits
Johan Heine

11.1 INTRODUCTION

In order to minimise losses, the standing rule for all firefighting operations is to get a fire under control as soon as possible, and to either contain or to extinguish it. A lesson learned in South Africa is that speed “within the parameters of safety” is critical. Equipment therefore has been adapted to live up to this expectation. Smaller tanker units (1500 to 2500 litre capacity) with high-speed capability are now becoming the norm due to the successes of the system. However, the most cost-effective unit is still the Bakkie-Sakkie/Pumper Unit. Equipment is only as good as the operator thereof (the weakest link in the chain). Frequently it is found that operating expenses are on the increase. Post-mortem are indicating that the problem can be attributed to the following:

- Poor readiness and reaction time.
- Bad management.
- Poor planning.
- Bad coordination of resources.
- Poor maintenance programmes.
- Lack of knowledge, skills and practical experience.
- Poor attitude from the workforce.

People remain the backbone of a successful firefighting operation. By educating them well and providing the necessary resources to do their work effectively, losses due to fire can be minimised.

11.2 PERSONAL PROTECTIVE EQUIPMENT

Protective equipment recommended for people working on the fireline:

- 100% cotton overalls. No nylon or synthetics are allowed because these melt and can cause severe burns.

- Leather safety boots without steel cap (steel cap not relevant).
- Safety helmet with visor. (Standard. Visor is very important.)
- 100% cotton T-shirt.
- 100% cotton balaclava.
- Standard pigskin gloves.
- Fire resistant goggles.
- Hardhat with a wire-mesh face shield (not recommended).

11.3 FIREFIGHTING HAND TOOLS

Keep the tools simple. Extinguishing or containing a fire with a wet bag or a broken-off branch is far better than waiting for the experts to arrive. This tendency is picked up typically with workers downing tools when the fire tender arrives, accepting that their role is now complete and that the “trained” personnel must perform their duties.

11.3.1 Selection of Tools and Availability

A beater stock for at least one plus one third of the work force to supply neighbours or helpers in case of large fires, is recommended. To ensure recovery, marking of hand tools (colour-coded rings around handles) is essential.

11.3.2 Tool Maintenance, Use and Storage

Handles

- Ensure that the ends of handles fit the hand of an ordinary person.
- Unnecessary weight in the handle increases premature fatiguing of people fighting fires.
- Must be smooth.

Heads of equipment

- Check frequently for tight fitting.
- Maintain cutting edges frequently.

Storage

- Clean properly after use and wipe metal parts with an oily rag.
- Clean the remainder of the tool with clean water and soap.

11.3.3 Description of Hand Tools

The most common hand tools are:

Axes/hatchets

Mainly used for clearing shrubs and woody materials in the fireline and during mopping up.

Beaters

A wooden handle fitted with conveyor belting cut in a specific shape with either holes or “fingers”. Used to smother the fire by overlaying the beater flaps in rhythmic beating by trained firefighters. Must not be lifted above shoulder height due to the risk of tossing burning materials over. These are much more effective than branches or wet hessian bags.

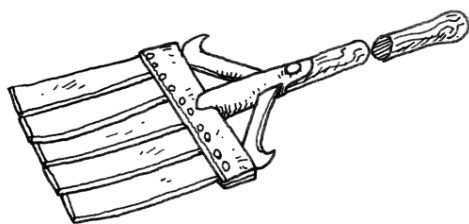
Bowsaws

Used for opening roads and cutting smaller trees.

Chainsaws

Mainly used for clearing a fireline in heavy fuels and felling snags, as well as logs in smaller pieces for clearing during mopping up. Only trained workers to use this dangerous tool.

11.1



Knapsack sprayers/backpacks

Useful in controlling slow spreading fires in light fuels. They can be used to follow-up the motorised firefighting equipment, in spot fires and mopping up. They are especially useful if used in conjunction with hand tools.

Rake-hoes/McLeods

A combination of a hoe and rake used primarily for preparing fireline/tracers.

11.4 ALTERNATIVE FIRE EXTINGUISHING METHODS

11.4.1 Fire Bombs

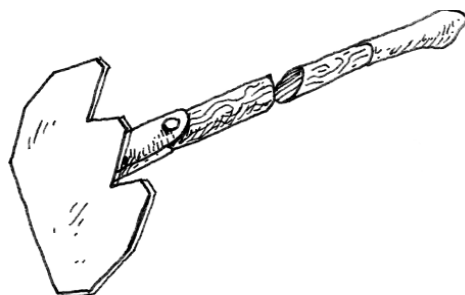
Five kilogram plastic containers, holding approximately 80% water, 20% chemical retardant, 40 g of gunpowder and a fast fuse. The extinguishers are supplied in fours in plastic carriers. They are easily activated by simply plucking out the fuses and placing them in a diagonal line in front of the oncoming fire.

They are particularly useful in stopping run-away fires in fynbos vegetation, montane and savannah grassland. For fires in slash they have more limited – but still a very useful – role to play. They cannot knock out slash fires entirely, but neither can any other firefighting equipment!

Figure 11.1. Typical fire beater (or “swatter”) (Heikkilä et al., 1993).

Figure 11.2. Example of Rake-hoe (Heikkilä et al., 1993).

11.2



They do, however reduce the fire intensity to such low margins that smaller equipment can take over the job of mopping up.

11.4.2 Impulse Technology

A system launched during 1994 and now being used by more than 10 000 firefighters all over the world. The system consists of a water supply, pressurised oxygen tank or compressor and an impulse gun or cannon.

Impulse technology discharges the extinguishing agent (normally water) in a matter of milliseconds at a very high velocity right into the seat of the fire. Twenty-five bars of air pressure in the pressure chamber in the impulse gun provide the high discharge velocity. The extinguishing agent is pressurised to six bars into the water chamber of the impulse gun. The shot is triggered by a high-speed valve, which lies between the two chambers. Air resistance breaks the water down to minute particles, so that the cooling surface of one litre of water is increased from the normal 5.8 m² to 60 m², thus reducing the temperature in confined space from 1000°C to 40°C in seconds.

The impulse shot hits the fire at approximately 400 km/h using the high kinetic energy to penetrate.

The system increases the water efficiency due to the following:

- The smaller the size of the water droplets, the greater their absorption capacity.
- The higher the droplet velocity, the greater the amount of water that reaches the base of the fire.

11.5 FIRE PUMPS

Factors that influence the selection of a pump for firefighting:

- The need to conserve and/or stretch water as much as possible at the scene of a fire.
- Many a small fire became an inferno due to the fire tender departing for refilling at a critical time.
- The quality/cleanliness of water used for fire-fighting. A piston pump is highly intolerant of sand, while a centrifugal pump is more tolerant. However, a strainer to minimise uptake of foreign particles, must always be fitted.
- The quality of service, maintenance and spares supply from the supplier of equipment.
- Funding available and price.
- Terrain (in mountainous areas, high-pressure pumps with a minimum of 25 bar pressure, are a necessity).

If funding is in short supply, consider the following alternatives:

- Boom sprayers with the boom-arms removed fit inbetween tree rows and provide a critical supply of water for initial fire suppression.
- Connecting the bottom-ends of several empty

210-litre drums on a flat bed truck or tractor-trailer to create a water tanker to supply smaller units (e.g. the boom sprayers).

11.5.1 Types of Fire Pumps

Various brands are available on the market. The following types have proven themselves in fire-fighting:

- *Centrifugal – single impeller*
High volume, low-pressure pump. Units on LDV's. Recommended standards:
 - Self-priming.
 - 364 litres per minute.
 - High pressure up to 72 metre / 7.2 bar.
 - Engine at least 3.7 kW.
- *Fire tenders*
Recommended standards:
 - Self-priming.
 - 1600 litres per minute suction.
 - 600 to 1000 litres per minute delivery.
 - High pressure between 50.0 metres / 5.0 bar and 70.0 metres / 7.0 bar.
 - Engine at least 12 kW.
- *Centrifugal – twin impeller*
High pressure, low volume pump mainly used in mountainous terrain. Recommended standards:
 - Twin impeller (standard)*
 - Self-priming.
 - 200 litres per minute suction at 3.0 metre head.
 - 250 litres per minute delivery at 70.0 metre head.

- High pressure up to 80 metre / 8.0 bar.
- Engine at least 12 kW.

Twin impeller (wide)

- Self-priming.
- 200 litres per minute suction at 3.0 metre head.
- $\pm$ 600 litres per minute delivery.
- High pressure up to 110 metre / 11.0 bar.
- Engine at least 12 kW.

• *Piston*

Small unit

Recommended for self-contained units on the back of LDVs. Recommended standards:

- Self-priming.
- 18.5 litres per minute delivery.

- High pressure up to 400 metre / 40.0 bar.
- Engine at least 2.6 kW.

Large unit

Unit 1: Recommended standards:

- Self-priming.
- 40.0 litres per minute delivery.
- High pressure up to 400 metre / 40.0 bar.
- Engine at least 3.75 kW (5 hp).

Unit 2: Currently popular with institutions fighting fires in rural areas (veld, forest and shacks). Recommended standards:

- Self-priming.
- 130.0 litres per minute delivery.
- High pressure up to 400 metre / 40.0 bar.
- Engine at least 15.0 kW (20 hp).

Table 11.1. Pump criteria

Pump type	Advantages	Disadvantages
Centrifugal (Single and twin impeller)	Ability to handle large particles in the water without damage to the impeller. Nozzle can be closed at random for short periods (risk of pipes bursting). Types available: • Low pressure, high volume. • High pressure, low volume (maximum $\pm$ 10 bar). Can be connected in parallel and series.	Connections on suction hoses must be airtight.
Piston	Good filter system required on suction. Pressure relief/bypass valve must be standard on the unit (nozzle can be closed). Conserves water. High pressure (up to 40.0 bar) Very light hose. Easy to handle.	Cannot be connected in parallel or series.

11.5.2 Use of Fire Pumps

The golden rule for a pump is “never restrict the input”. Restriction causes water cavitation at the impeller of the pump, resulting in premature failure.

It is better to have two smaller independent pumps that can either run individually or be connected in parallel (to provide volume) or series (to provide pressure). A dead engine has been the reason for many small fires becoming an inferno. The twin engines provide one standby that is always available.

Friction loss

Small diameter hose, long lays of pipe and fittings in the hose cause friction loss. Various tables are available for different hose and hose diameters to calculate friction loss (consult your local hose supplier).

Maintenance

The engine and pump work in the extremes of bad conditions. On the one side dust (travelling to the fire) and on the other soaking wetness (converting the dust into a grinding paste). Unless maintained frequently, premature failing is guaranteed.

A simple, but very effective routine system (ignore hours worked) for maintenance during the fire season is as follows:

- After every fire – allow for engine to cool and wash down with water and soap.
- Every Friday – clean engine air filter.
- Every mid-month Friday – drain engine oil and replace. Clean spark plug.
- Last Friday of month – drain engine oil and replace. Replace air filter. Replace spark plug, remove, clean and lubricate the starter rope assembly.
- Ongoing – check that it is done!

Overnight storage in cold areas

Many a pump and ball-valves have been lost due to freezing. The following have been applied with great success:

- *Drain the system of water to prevent electric shock when using an electric drill.*
Ensure that the ball-valve handle is in the closed position. Drill a one-millimetre hole into the side of the ball valve in the centre of the housing directly below the nut holding the handle. This hole will allow water that is trapped inside the ball to ooze out, allowing for expansion of the remaining water in case of freezing.
- Add anti-freeze or diesel or paraffin through the priming filler cap on the pump housing every night to prevent freezing of the water in the pump housing.
- Cover the pump and engine with a locally manufactured “blanket”.

Post-fire season storage

To prevent damage to the pump and engine during prolonged periods of storage, the following applies:

- Run the engine until the fuel is exhausted.
- Drain and fill the sump with fresh oil.
- Remove the spark plug and add one teaspoon

of oil. Turn the engine to lubricate the top parts of the cylinder and head.

- Drain the pump housing of all water.
- Close all openings to prevent insects and rodents from gaining access.

Removal from storage

Prior to starting the engine, pull the starter rope or crank the engine with the starter, with the spark plug lead disconnected, to ensure that the engine and pump is free to rotate. If it is free, fill the fuel tank and commence with the normal starting procedure.

11.5.3 Fire Pump Accessories

Hoses

Ensure that there are always spare rubbers or “O” rings available with the pump for the different kinds of hose connections. If working with neighbours, compatibility is very important.

Canvas

Standard used for forestry firefighting is the 40-millimetre percolating lay-flat hose.

Advantages:

- Resistant to scorching when wet.
- Mobility between trees.
- Volume of water for hot fires.

Disadvantages:

- Maintenance and drying.
- Rolling and firmness of rolls for unrolling.
- High friction loss unless lined on the inside.

Rubber

Recommended:

- 25-millimetre diameter for single impeller centrifugal pumps.
- 20-millimetre for twin (wide) impeller centrifugal pumps.

Advantages:

- Lifespan.
- Resistant to scorching.
- Easy to maintain.
- Low friction loss.

Disadvantages:

- Cost.
- Weight.

PVC/Dragline

Recommended:

- A minimum of 25-millimetre diameter.

Advantages:

- Cost effective.
- Light weight
- Easy to maintain.

Disadvantages:

- Risk of melting when laid over burning materials.

Nozzles

The ideal nozzle has the following properties:

- Adjustable to jet or mist spray.
- Adjustable modes in jet or mist spray.
- Provides a water curtain for cooling the nozzleman.
- Is fairly “cheap” (they get lost easily).



The nozzleman's chief objective should be to see that no more water than the situation demands is used. Each drop of water should be placed as to do the maximum amount of work in cooling the fuel.

Class A foam

Class A foam is a chemical which, when added to water in the right amounts, creates bubbles with a lower density than water. The bubbles stick to the fuels and gradually release the moisture they contain. The bubbly water absorbs heat more efficiently than plain water. The ratio is normally 0.1 to 1.0%.

Introducing air into the water/foam mixture makes the foam. There are several proportioning systems that can be classed as manual or

automatic systems. The cost of the equipment and user friendliness will determine your choice. The critical success factor for applying foam is a 100% familiarity with the proportioning system and chemicals being used.

Gel

Although new in South Africa, it has been tested extensively overseas with very good results. It is different from a foam in that it has a gluey/sticky appearance resulting in better oxygen removal.

Wetting agents

Are chemicals that – when added to water – will reduce the surface tension of water and increase penetration and spreading capabilities. These

Figure 11.3. Small pumper unit with hoses and other hand tools (Photo M.F. Calvin).

types of products are especially effective during the mop-up stage of a fire. They are more efficient for this use than class A foam. Wetting agents are added directly to the water tank.

11.6 PUMP STORAGE

Maintenance prior to storing for the non-fire season is critical to prevent rust and decay of equipment. (e.g. a teaspoon full of diesel, anti-freeze or oil added to water in pump housing to prevent rust).

Drain the pump unit of water. Run the engine until fuel is exhausted (petrol gel during prolonged storage). Drain and fill sump with fresh oil.

Before starting the pump after storage, check to see if it is free to rotate by cranking with the ignition in the off position.

11.7 FIRE LIGHTERS

Home-made devices:

Matches

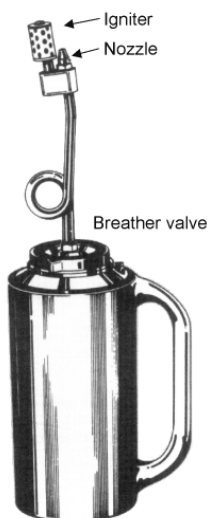
Used to ignite grass, which is dragged with the rake-hoe, to spread the fire into new areas.

Torch

Splinter the end of a dry stick (approximately 50 mm in diameter) with an axe/hatchet. Once on fire it forms a torch for easy igniting of light fuels.

Maize cob soaked in diesel

The end of a piece of wire (approximately 100 cm in length) is rolled around a maize cob. The cob is soaked in diesel. It provides a handy igniter, burning for long periods.



Drip torches

11.4

Used for starting back-fires or for the burning out of a fire-line. Normally used in a swinging motion, spreading the burning fuel into the area to be burned.

Do not exceed mixture rate of three parts diesel to one part petrol due to the danger of being too "hot".

11.8 HEAVY MACHINERY

Bulldozers

Bulldozers are indispensable for clearing a fireline at major fires, and a MUST on high fire danger index (FDI) days. Be extremely cautious if a bulldozer is working on slopes above personnel, as it tends to dislodge rocks or other things that can roll.

Agricultural equipment

Tractors, terrain permitting, with ploughs/discs/rotovators can be very useful for clearing a fireline where speed is required.

Mobile (ground) firefighting units

The selection of firefighting equipment depends on the following:

- Skills level of the operators involved in the firefighting operations.

Figure 11.4. Drip torch (Heikkilä et al., 1993).

- User-friendliness.
- Availability of water (determines pump output).
- Average distance from filling points (determines pump filling ability).
- Availability of and type of additives to “stretch” the water supply.
- Interconnectivity of hoses and suction hoses with neighbours.
- The quality of service, maintenance and spares supply from the supplier of equipment.

Note: Rollover protection and seatbelts for firefighters on fire tenders (complete firefighting units) have become a necessity due to the number of accidents with high-speed vehicles.

Bakkie-sakkies (“pumper units”)

Selection of the “ideal” unit:

- Unobscured views to the vehicle’s rear.
- No obstruction of access to the starter mechanism of the pump motor, valves and hose reel(s).
- Baffles fitted in tank to prevent water surge when stopping suddenly or turning vehicle.
- Centre of gravity as low as possible on the vehicle.
- Anchor points provided to prevent slipping of the unit.
- The weight of the unit should also allow for the transport of labour, handtools, etc.

Fire trailer and slip-on (or “drop”) units

Similar to the above but, ideally:

- All pumps and controls should be situated at the back to allow the pump operator to have unobstructed views to both sides of the vehicle. This enhances communication with the firefighters on the hoses as well as the nozzleman.
- Hose reels should be mounted as low as possible to ease the rewinding of the hoses.

Tanker units

The latest tendency in South Africa is replacing steel with new generation plastic tanks. This has resulted in major weight reductions, increased stability of vehicles and increased volumes of water that can be transported legally.

Complete fire fighting units

The tendency in South Africa is multi-purposing of vehicles by using slip-on units that are equally effective.

It is impossible to make recommendations on the “ideal” complete firefighting unit due to the variety available. Factors that will influence the kind of vehicle to be used are the following:

- Preferred method of firefighting. Direct attack on the fire line may dictate a 4x4 vehicle.
- Road density. A lack of roads may dictate moving in-field, therefore necessitating a 4x4 vehicle.
- Soil conditions. Wet or dry conditions in combination with a lack of roads may dictate a 4x4 vehicle.

11.5



- Steepness of roads and terrain. Too heavy a vehicle will tend to snap side-shafts.
- The width of roads. Too long a vehicle will not be able to turn around on narrow roads.

“Word-of-mouth” advertising by existing users is a reliable source of information. Just double-check with other users of the same equipment or ask the supplier for a list of references to contact.

11.9 AERIAL FIREFIGHTING

Fixed wing aerial firefighting was introduced in South Africa, in the KwaZulu-Natal Midlands, during 1980. This method of firefighting expanded throughout the eastern side of South Africa to 15 Spotters (C182–C206) (Bird Dog, Reconnaissance

and patrol) aircraft and 28 seats (single-engine air tanker), which include 1500 l to 2000 l polish-built single-engine PZL M-18 Dromaders, Air Tractors and SR2 Thrushes. The advantages of these types of aircraft are quick response and low costs.

The use of helicopters in firefighting operations in South Africa has until 1986 only taken place on an ad hoc basis, at the various forestry and catchment centers throughout the republic. The high helicopter operating cost had not justified their application on a large scale in South Africa.

Since 1986, a variety of operations have been carried out in the Western Cape and Eastern Escarpment with varying success.

Figure 11.5. Helicopter with water bucket fighting a fire in the Western Cape of South Africa. (Photo M.F. Calvin).

The original motivation was to fill the resources gap created by the reduction of firefighting staff and improve initial attack time. However, there was a lack of insight into true functions and capabilities of the aircraft.

Aircraft, on the other hand, can contain a fire line, and a back-up ground crew increases the efficiency of the aerial attack.

The pre-conception that large volumes of water applied to the fire was the primary requirement to suppress it overshadowed the real primary requirement and true value of aircraft, which is fast “first strike” containment.

11.9.1 Fire Suppression Using Aircraft – Tactical Support with Aircraft

The most effective application of aerial attack is on small, aggressive fires that exceed the capacity of ground forces to control by direct attack. Aerial attack has the potential of checking or of reducing the energy output of such fires sufficiently for ground forces to gain quick control.

The second important application service of aerial attack is that of giving ground forces more time to get to a fire. They wet down the area in which a fire is burning and are usually successful in checking its spread and preventing crowning until ground forces can get to it to complete control.

The third use is in aerial support of ground operations in the firefighting (control) of a large fire. This use should only be done in close co-ordination with the fire boss. Under such conditions the operation is very costly and should be placed under an air-attack boss as the application is very specialised and requires specialised skills to perform efficiently.

Because of their manoeuvrability, helicopters offer a much higher potential for effective attack on fires from the air. The offsetting factors are a much more limited payload and higher cost.

Helicrews are special fire crews, equipped and trained for transport to fires by helicopter. The special advantage of this kind of transport is that of placing firefighters at almost any location, quickly and without fatigue.

There are several factors that will limit the effective use of aircraft:

- Terrain.
- Strong winds.
- Sun's position and shadows.
- Tall trees or snags, power or telephone lines, elevation, smog and dense smoke.
- Fuels and extreme fire behaviour, turnaround time, retardant or suppressants.
- Aircrew experience and airboss attack plan and application.

The fire boss, or Aerial Attack Officer, must establish objectives and set priorities for the air operation.

The fire boss must have an attack plan and communicate it to the air attack officer and ground support personnel. He must ensure that drops will be followed-up by ground forces, that there is no over-management of the air operation, and also consider the following:

- Do the values at risk justify the use of aircraft?
- Are the weather conditions conducive to safe and effective use of aircraft?

- Does the fire's behaviour and potential justify aerial support?
- Bird Dog, Lead Plane and Air Attack Plane?

11.9.2 Spotters – Air Attack Officer (Spotter Pilot, Air Attack Officer, Aerial Fire Boss)

The primary function of the Spotter Pilot/Air Attack Officer is to coordinate the air operation and be responsible for the safety of all aircraft assigned to the fire. He/she can also assist in coordinating the ground forces and in providing vital intelligence on the fire's behaviour. Assistance to the responding firefighting resources with access routes, water sources, etc. can be provided.

Spotter aircraft provide a platform for the air attack officer to control and coordinate the aerial operations. The air attack officer should work the aircraft in close coordination with ground forces. Pilots and air attack officers must be prepared and properly trained to fly the spotter aircraft. The operation must be cost effective, efficient and safe.

Quite often the spotter planes are the first aircraft to arrive at a fire and, in many instances, solely handle the initial attack function.

The Spotter Pilot/Aerial Attack officer will direct the bombers/tankers in, in order to make their drops by holding off above and giving verbal instructions and corrections to the bombers once he has them in sight.

Flying spotter planes on firefighting operations is complex, tedious and stressful. Like the pilot flying hard instruments for long periods, the stress and workloads vary throughout the period of the flight. The key to a long life is the making of the correct decisions at the right time and not

allowing high stress loads to corner one into making the wrong decisions at the wrong time.

11.9.3 Water Bombers (Air Tankers)

At this stage, 25 single-engine air tankers (seats) are used in southern Africa to fly aerial firefighting missions. They are mainly PZL M-18 Dromaders, Air Tractors and SR2 Thrushes. The advantages are that they are quick to respond. All Bomber pilots are trained to be initial attack qualified before he is allowed to drop on a fire line. Experience has shown that when the danger of fire is high, the effectiveness of a wildland firefighting system depends on its ability to react quickly. Fires must have covered less than one hectare at the time of initial attack. A good system is founded on the following basic principles:

- Detailed assessment of the hazards, expressed as an index permitting a meaningful quantification of risk. This involves traditional forecasting based mainly on meteorological data.
- Preventive deployment of resources in order to suppress small fires in the shortest possible time, before they can develop into hard-to-control conflagrations.

Very rarely can an aerial attack extinguish a fire without ground support, and the following up of ground crew with the construction of a fire line, will ultimately control the fire.

11.9.4 Helicopters

Helicopters are valuable tools that can be used for both firefighting and logistical support. In South Africa, helicopters are used throughout the

country. Civilian as well as military helicopters are used extensively where fixed wing support facilities are not available. Helicopters are very versatile and have some unique capabilities, which are as follows:

- Helitack or Helicrew – when a crew of highly trained and experienced firefighters are teamed up with a helicopter, they can be a very effective initial attack tool and can be effective almost anywhere they are able to land.
- Water delivery – helicopters are very effective water delivery tools and can usually fill up at the closest water source.
- Transportation – in order to move people or equipment quickly.
- Reconnaissance – since a helicopter can move around slowly, or even hover over a spot, it is the perfect platform from which to a fire reconnaissance.
- Medical evacuation – they are especially useful for moving injured personnel to medical facilities.
- Initial attack – helicopters in the initial attack role can often be problem solvers, dealing with spot fires, gaps in the fire line and personnel and structure protection.

Helicopters are very dangerous to be around and safety rules must be kept in mind when in or around helicopters.

When helicopters take on the firefighting role, size does make a difference. Heavy helicopters with large lift capabilities may be more useful in aerial firefighting than light rotorcraft.

11.9.5 Fire Suppression using Aircraft: General Notes

Extensive wildfire/forest fire suppression experience over 20 years has led to the following conclusions about using aircraft for aerial fire-fighting in southern Africa:

- Ground-based suppression methods can and will continue to be the primary method to control wildfires.
- Agricultural fixed-wing aircraft and medium lift helicopters with suspended buckets are a cost-effective mix of aircraft for direct attack.
- Firebombing must be followed up by ground support forces, and is not effective in stopping large and intense fires.
- Because there is a considerable variation in the fire season severity from year to year, flexibility in financial commitment to aircraft fixed cost is essential for overall cost-effectiveness.
- For firebombing to be efficient and effective it must be mandatory that aircraft are available at call, are rapidly dispatched and that travel time is short.
- Air operations must be effectively integrated into the fire fighting organisation, competent personnel must direct air operations and effective ground crew must be in place.

Aircraft are only as efficient as the organisation allows them to be and the provision of proper direction and support is critical to achieving the overall fire control objective.

11.9.6 Communication

Communication is a vital element of a coordinated firefighting effort and is critical in any firefighting operation. It is the thread that ties all the various elements of a firefighting organisation together. If there is no communication, there is no organisation. During a fire there are specific radio nets for certain functions, such as command, tactical, air-to-air and air-to ground. These nets are critical during fire operations.

The fire communication system may be seen as the nervous system of the fire organisation, enabling quick awareness of external stimuli at some central point and quick response. It provides the essential link that enables a group of men to work together at a fire. It is the means by which dispersed supervision, cooperation and coordination of activities can take place.

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12

APPLICATION OF PRESCRIBED BURNING

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12.1 INTRODUCTION

“Prescribed burning is both a science and an art requiring a background in weather, fire behaviour, fuels, and plant ecology along with the courage to conduct burns, good judgement, and experience to integrate all aspects of weather and fire behaviour to achieve planned objectives safely and effectively” (Wright & Bailey, 1982).

There are two primary types of fires, wildfire and prescribed fire. The term *wildfire* refers to any natural fire or a fire unintentionally set by humans. This may range from a low-intensity fire, which may be controlled easily, to a major conflagration that cannot be controlled due to fuel characteristics and extreme weather conditions. A *prescribed fire* refers to a fire that is intentionally ignited to accomplish pre-planned objectives; this fire is kept under control at all times. The effects of a wildfire, however, may also accomplish pre-planned resource management objectives.

In view of Africa being referred to as the *Fire Continent* (Komarek, 1965) prescribed burning has become recognised as an important ecological factor in the grassland and savanna ecosystems. Research investigating the effects of the fire regime on the biotic and abiotic components of the ecosystem has been conducted in these regions since the early period of the 20th century. This has led to a general understanding of the effects of type and intensity of fire, and season and frequency of burning on the grass and tree components of the vegetation, i.e. the effects of the fire regime. This, in turn, has clarified the use of fire as a range management practice and viable prescribed burning programmes have been developed for the grassland and savanna areas used for livestock production and for various forms of wildlife management. There are a number of reasons why resource managers conduct prescribed burns in natural ecosystems:

- Wildfire hazard reduction by fuel reduction.
- Biodiversity conservation.
- Range management for domestic livestock and wildlife husbandry.
- Improvement of wood and fibre productivity;
- Selection of tree species.
- Disease control.
- Watershed management.

Burning has acted as nature's "scavenger" since the beginning of time by removing accumulated dead vegetation and recycling the nutrients. In most terrestrial ecosystems, vegetation grows annually, senesces, and some of it remains behind to accumulate year by year. As these fuels build up they can shade and suppress the live vegetation as well as become a fire hazard. Fuel accumulations often vary across the landscape; variable amounts of fuel, weather and topography cause fluctuations in fire intensity and related factors during prescribed burns, thus promoting biodiversity.

Many prescribed burns in natural ecosystems are planned to alter habitat characteristics, forage or browse production, or quality. Fire can be quite flexible in its potential to alter natural or human-made ecosystems, provided the user is skilled and knowledgeable in pre-burn planning, the implementation of the burning operation and in post-burn management.

Burns to control bush are conducted to change woody plant structure and biomass. This can be useful to bring palatable browse within browsing height of herbivores and to open up vegetation

for game viewing or sport hunting purposes on game reserves and ranches.

While prescribed burning in the grasslands of Africa has been maintained as an important management tool, the use of controlled fire in some shrublands, such as fynbos in South Africa, has declined during recent years. However, it may soon regain its important role in the region, to reduce the size and occurrence of wildfires. The role of fire in fynbos is complex. Suitable burning days are restricted and burning of fynbos growing on steep terrain should only be attempted by experienced burners. However, the vegetation should not be left unburned until it becomes too old for controlled burning, as by then the senescent fynbos becomes too dangerous for prescribed burning application.

With the introduction of industrial timber plantations in southern Africa, prescribed burning was used to manage the natural fuel base, as well as to reduce slash and other plantation fuels. Today prescribed burning is mainly used in forestry plantations for fire protection, but it is also used selectively as a fuel reduction measure. All the trees established in plantation-form in forestry regions originate from fire-dependent ecosystems elsewhere and were planted within natural ecosystems where fire plays an important role in the maintenance of biodiversity.

Prescribed burning has to be applied selectively and correctly in the various natural and man-made vegetation systems of Africa to satisfy a range of objectives, and in this chapter procedures and practices will be discussed.

12.2 APPLICATION BASE

12.2.1 African grasslands and savannas

Prescribed fire is essential, and is commonly being applied in all ranges of African grassland and savannas. In savanna, moisture is usually sufficient to permit trees and shrubs to maintain populations, but not enough to exclude perennial grasses. A prolonged dry season is a prominent feature and then the grass layer becomes dry, highly flammable and susceptible to burning. Both woody and herbaceous species are adapted to fire and have evolved with it in the savanna environment. Many tree species are able to endure low and moderate intensity surface fires, but high intensity passive (intermittent) crown fires will top-kill most trees. The trees that are top-killed usually sprout from dormant buds. The tropical savanna is one of the most frequently burned ecosystems in the world (Bailey, 1988).

Ecosystem managers should realise that there is always going to be fire in savannas, whether as a prescribed fire or as a wildfire. Fire is a natural environmental phenomenon that normally does not produce serious residual effects. Fire alone, or fire and grazing together, are ecological management tools that have the potential to manipulate savanna vegetation favouring productivity of the desired resources. Most wild herbivores and livestock prefer to graze or browse inside recently burned areas rather than in unburned areas.

Thus there must be a management plan in place prior to the fire to cope with the reality that wild and domestic herbivory must be sufficiently managed for one or more years after fire to prevent overgrazing and resource degradation.

African savanna is usually burned for the

following reasons (Bailey et al., 1993):

- Security burning to provide fuel breaks, protect buildings and other structures for use during other prescribed fire applications, or to protect against wildfire.
- Reduce the fuel hazard and to remove accumulated dead vegetation.
- Provide improved forage quality or quantity.
- Increase biodiversity.
- Bush control.

Therefore the main purpose of conducting security burning is fire hazard reduction. Security burning reduces the chances of wildfires or other kinds of prescribed burns entering an area where fire may damage property or infrastructure, such as buildings, camps and other inflammable infrastructure. The other type of security burning is to provide fire breaks (fuel breaks) for the purpose of restricting a fire to a particular location or property. These fire breaks are called security fire breaks.

Any attempt to prevent fires from entering a property from neighbouring land will involve exorbitant costs and is usually not required. It is therefore more cost-effective to reduce the probability of fires leaving the property into neighbouring areas where they could cause damage to property.

Prescribed burning is an important and often essential range management practice in areas used for livestock farming, whether it be for commercial or subsistence purposes.

The most important factors to consider when planning a burning programme are the reasons

for burning and the appropriate fire regime to be applied.

The current view amongst range scientists and progressive livestock farmers on the permissible reasons for burning rangeland are that fire can be used to:

- Remove moribund and/or unacceptable grass material.
- Control and/or prevent the encroachment of undesirable plants (Trollope, 1989).

These are the basic reasons for burning grassland and savanna vegetation in Africa, and both are applicable to areas used for commercial or subsistence livestock farming. One of the often-quoted reasons for burning rangeland is to stimulate an out of season “green bite”.

This is often done during summer, or late autumn or winter, to provide green nutritious re-growth for grazing by livestock. This practice is completely unacceptable because:

- It reduces the vigour of the grass sward.
- It reduces the basal and canopy cover of the grass sward.
- It increases the runoff of rainwater.
- It can result in accelerated soil erosion. (Trollope, 1989; Everson, 1999)

This malpractice cannot be condemned enough as it has been responsible for the drastic deterioration in range conditions over extensive areas of southern Africa. Unfortunate examples of this incorrect use of fire can be seen in South Africa in the north-eastern Cape Province, the Transkei,

KwaZulu-Natal and the eastern mountainous grasslands of Mpumalanga.

It has been suggested that fire can be used to control ticks, which cause tick-borne diseases in livestock, but this reason is generally discounted because ticks persist in areas which are frequently burned. However, Stampa (1959), in a study of the Karroo Paralysis Tick in the Karroid *Merxmüllera* Mountain Veld in South Africa, has shown that this parasite can be successfully controlled by altering the micro climate at soil level and thereby creating an unfavourable habitat for this organism, resulting in its disappearance. Similar evidence has been collected by Trollope and Trollope (2001) in the Ngorongoro Crater and in the Serengeti grasslands of Tanzania where controlled burning by nomadic Masai pastoralists has resulted in a significantly lower incidence of ticks where this practice is applied. The incidence of ticks can be high when the grass sward is in a moribund and unacceptable condition for grazing by livestock, or when it is encroached by excessive densities of trees and shrubs, therefore using fire for the aforementioned permissible reasons will have the added benefit of minimising the incidence of ticks in areas used for livestock husbandry.

Finally, it was also shown that frequent fires favour the abundance of the highly productive and palatable grass species, *Themeda triandra*, in southern African grasslands (Scott, 1971; Dillon, 1980; Forbes & Trollope, 1991). This raises the possibility of using fire to improve range conditions by increasing the abundance of valuable forage species like *Themeda triandra*. Inadequate information is currently available to legitimise

this reason for prescribed burning of *veld*, but with appropriate research on the response of key forage species to fire it could be considered as a valid reason for burning rangeland in the future.

12.2.2 Fynbos

In fynbos, prescribed burning is normally applied for two reasons: (a) To maintain biodiversity by applying fire in the form of block burning, and (b) as a fire protection measure in the form of block burning application or burning of fire breaks. The timing of these burns in terms of season of burn, burning frequency and fire intensity is complex and sometimes difficult to comply with. To complicate matters further, natural fires (e.g. lightning fires) and unnatural (mostly human-caused) fires disrupt prescribed burning programmes, particularly if this occurs prematurely, when the vegetation has not yet reached the mature/senescent phase. Delayed prescribed burning – or alien weed infestation – can result in hazardous biomass accumulation, which in turn can form the basis for extremely high fire intensities during wildfires, which is detrimental for certain seed stores.

The use of fire in the more arid fynbos communities, such as Renosterveld, may require lower frequencies of burning than in fynbos growing in higher rainfall regions because of restricted biomass production. Use of fire may in some cases have to be postponed when the vegetation age exceeds 15 years, or even 20 years, because the biomass is just too sparse to carry a prescribed burn.

However, these long delays also expose the vegetation to increased wildfire threats,

particularly where lightning-caused wildfires are common at high altitudes in mountainous areas.

12.2.3 Industrial Plantations

Prescribed burning inside plantation stands can be applied in two ways, namely: (a) By burning of slash after clearfelling and exploiting the final tree crop, or (b) inside tree stands under the crown canopy. Both methods have been recognised as acceptable management tools in some countries for wildfire hazard reduction, site preparation for planting, and sometimes for other objectives, such as provision for grazing, weed control or ecological reasons – e.g. to combat insect attacks. In southern Africa, slash burning after clearfelling is mainly applied to reduce slash fuel levels and in this way to facilitate re-establishment of trees, while the application of fire inside tree stands is mainly for fire protection when these areas form part of bufferzones or fire breaks.

For some decades there has been a resistance against the use of slash burning in pine stands in the summer rainfall areas of southern Africa because of problems with *Rhizina undulata*. During the 1990s this problem was grossly exaggerated, bringing the use of slash burning almost to a standstill. The reality was (and still is) that the occurrence of *Rhizina* is normally restricted and patchy, and that it appears mostly in cycles, with years of total absence. The problem can also be overcome by delaying planting of trees by a few months. However, after some wildfires *Rhizina undulata* was observed to attack surviving trees, causing serious tree mortality (own observations).

Slash burning has also been found to provide an excellent method with which to combat the

fern *Gleichenia polypodioides* in the Cape forest regions, and to reduce accumulated *Pinus patula* litter loading at high altitude in the summer rainfall regions to manageable levels by improving fungal activity and in this way to increase decomposition rates.

The so-called “ash-bed effect” was also found to improve tree growth rates in the Tsitsikamma region of South Africa – on clayey soils with serious phosphate deficiencies – for up to seven years (De Ronde & Zwolinski, 2000). However, slash burning should be avoided on sandy (nitrogen-poor) sites, because it may cause serious nutrient deficiencies and fire should not be applied on steep slopes where it can cause erosion.

Prescribed burning is mostly applied in *Pinus* stands for fire protection purposes, particularly if plantation stands fall within bufferzones or within other strategic external fire breaks. Research programmes conducted have confirmed the potential for future application of prescribed burning in the Cape forest regions of South Africa, but use of the technique is still being debated by plantation managers. However, the technique is being applied at an increased scale in *Pinus elliottii*, *Pinus greggii* and *Pinus patula* stands, in the north-eastern Cape, the Highveld and other summer rainfall regions of southern Africa.

In the Cape forest regions prescribed burning inside stands (under the crown canopy) can be applied successfully as part of fire protection networks and to reduce accumulating forest litter, particularly where an absence of decomposition occurs. Its use to check the spread of the “Kyster” fern (*Gleichenia polypodioides*) has also been confirmed in various field experiments, while the

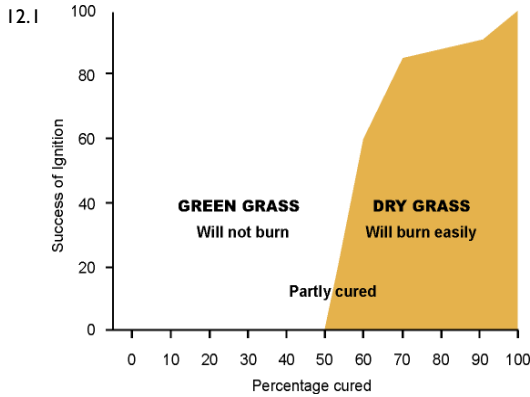
potential to use prescribed fire against other weeds is worth investigating (De Ronde, 1988). Prescribed burning inside pine stands elsewhere in Africa is recommended, particularly in even-aged tree stands planted with species such as *Pinus caribaea*, *P. elliottii*, *P. greggii*, *P. patula* and *P. taeda*. *Pinus elliottii* was found to be the most suitable for this purpose, as these trees are highly resistant against fire damage (De Ronde, 1988; De Ronde, 2001). Application of the technique is also more and more incorporated in fire protection systems of southern Africa, while its use in *Pinus patula* stands at altitudes of above 1400 m – as an alternative (or supplement) to slash burning after clearfelling – is considered in some forest regions as none of the other possible cures for this problem have proved to be economically viable.

To summarise, although the application base of prescribed burning inside plantation stands is still restricted, it has a lot of potential, together with slash debris burning after clearfelling (De Ronde et al., 1990).

12.3 FUEL APPRAISAL

12.3.1 Considering Grassland Age, Biomass Addition and Degree of Curing

Fuel refers only to combustible material (Chandler et al., 1983). Moist or wet plant material is not fuel because it will not ignite. The degree of plant curing becomes an important issue in determining when to initiate prescribed burns (Figure 12.1). Ignition will usually begin when green grass is partially cured, at between 50 and 60% curing. Ignition occurs with little difficulty when the grass is about 70% cured.



12.3.1.1 Fine Fuel

Fine fuel refers to grasses, forbs and leaves. Grasses and forbs are generally non-volatile fuels that ignite readily when dry and are consumed quickly. It is rare for grasses and forbs to produce firebrands during a burn. On the basis of their cured status, fine fuels can be divided into live (green) and dead fuel. Some fuels in some areas cure quickly (e.g. moist savannas) whilst others (e.g. arid savannas) cure more slowly.

12.3.1.2 Woody Fuels

In contrast, many woody fuels are also volatile fuels high in fats, resins and volatile oils, which often produce enough firebrands to create great danger of igniting fuels a distance ahead of the fire. Examples of volatile woody fuels are *Euclea crispa*, *Rhus lancea* and *Vitex rehmannii*.

Fuel refers only to combustible material. Lush, green, high-moisture living plant material is not fuel because it does not meet the basic criteria of being combustible. There are a number of factors that need to be considered with regard to fuel.

These are the amount of standing crop, the degree of curing and the compaction of the fuel.

Fire will not burn without sufficient combustible fuel. For fire to spread, it is necessary for there to be an adequate quantity and distribution of fuel across a landscape – any gaps without sufficient fuel will disrupt the spread of the fire front. The amount of fuel required to carry a fire varies considerably from ecosystem to ecosystem. A reasonable estimate of the minimal fuel load required for burning grassland is 1000 kg/ha of dry herbaceous fuel that is compacted near the ground. Taller herbaceous plants that have very little fuel lying on the ground require about 2000 kg/ha (Bailey, 1988). Trollope and Potgieter (1986) working in the Kruger National Park, South Africa, suggested that 1500 kg/ha was required to carry a fire.

With regard to grassland curing, annual and perennial grasses go through an annual life cycle where the plant produces new shoots, grows, flowers and senesces or dies. During spring grasses undergo a period of growth and would normally complete this in late spring or early summer. This is dependent, however, upon seasonal variables such as rain and temperature. A wet spring and rain in early summer will produce abundant growth, while little or no rain in early summer will accelerate the senescence and drying of grasses (Cheney & Sullivan, 1997). As the period of growth is completed, grasses lose their ability to draw moisture from the soil and begin to desiccate. When the plant becomes dormant or dies and loses moisture, this creates the potential for fire spread. Light to moderate frost, in moist infertile savannas (Van Wilgen & Scholes,

Figure 12.1. Illustration of the relationship between the success of ignition and the percentage curing of green grass.

1997) speeds up the curing process. Following frost, the plants soon become dry enough to burn, thus they become fuels, and the fire season commences. This is different from arid savannas in which the fuels lose moisture over time and cure more slowly. This annual cycle is termed curing.

Fuel load is a function of the age of the grassland, i.e. the time since the previous fire. Studies from Highland Sourveld illustrate how fuel loads increase as a function of time. In the first year following a fire, approximately 2020 kg/ha of fuel accumulates. Once this fuel has started curing, it can readily sustain a running fire, even under mild fire hazard conditions. Fire breaks are prepared in one year-old grassland with low fuel loads. After two years, fuel loads approximately double from the first year, to approximately 4700 kg/ha. Since present burning prescriptions for these grasslands call for a two-year burning cycle, this is the fuel load which is most commonly dealt with by managers. In low fire hazard conditions, fires in these fuels are controllable, but even under moderate conditions they may become uncontrollable. Thus many of the wildfires, which occur in the KwaZulu-Natal Drakensberg in South Africa, take place in two-year old grassland. Since the first seasons' growth is already fully cured, it is possible for two-year old grassland to burn in any month of the year. By five years, the total fuel load is 6090 kg/ha and after ten years a maximum of 7000 kg/ha is reached. The major portion of these fuels comprise of fine dead material, making them an extreme fire hazard. Beyond ten years these grasslands become moribund, causing the amount of fine fuel to drop to approximately 550 kg/ha after 20 years. At this stage the grasses are

invaded by woody species.

Fuel availability refers to the proportion of fuel (usually fine fuel), which will burn in a fire (Luke & McArthur, 1978). The available fuel is always less than the potential fuel depending on fuel moisture content. When annual winter fire-breaks are burned, for example, the moisture content is low and approximately 96% of the fuel is available. Most of this fuel is consumed in a fire with the post-burn fuel being in the form of ash. Although the biennial spring prescribed burns are applied under conditions of high fuel loads, moisture contents are high and only 70–90% of the fuel is available. The contribution of unconsumed (post-burn) fuel may represent up to 34% of the total energy.

12.3.2 Optimum Industrial Plantation Burning Seasons

In the winter rainfall area of South Africa (Western Cape) the best burning season is no doubt winter-time, whenever there is a dry spell between cold fronts with wet conditions. Monitoring weather patterns for optimum burning conditions with the assistance of the Cape Town Airport Weather Bureau is the best procedure to follow to decide when burning can be applied safely. The best time is about two to three days after the last rain has been recorded, when no rain is predicted for at least three days after the previous cold front went past the Cape (unpublished results from burning experiments conducted by C. de Ronde).

In the constant rainfall area of the Southern Cape and Tsitsikamma regions of South Africa, the summers are normally too dry and too hot

for prescribed burning application, while the south-easterly wind can also present problems. During the winter season, bergwind conditions can suddenly start blowing after a cold front swept past the coastal areas, and this can make prescribed burning problematic and even dangerous. The best seasons to apply prescribed burning inside even-aged stands are spring and autumn, i.e. from the end of September to the end of November, and during the months March and April. During these periods calm conditions can be experienced for days, presenting excellent burning conditions (unpublished results from burning experiments conducted by C. de Ronde).

In the summer rainfall area (the rest of Africa south of the Sahara), winters are too dry and dangerous for fire application inside plantations. Mid-summer may be too wet for prescribed burning in most cases, as regular thunderstorms do not allow the forest floor to dry out sufficiently, particularly in mature *Pinus patula* stands. Again, the best seasons for prescribed burning are spring and autumn. During spring, burning can be applied soon after the first spring rains (wait for more than 25 mm rainfall, as too little rain may not wet the forest floor completely down to the soil surface. Check the moisture status of the litter layer before burning is applied). During autumn, burning should be planned for two to seven days after good rain, depending on the fuel drying-pattern. Apply the burn during the morning, starting at approximately 09:00 so that burning can be completed by noon, before possible thunder-showers (various burning experiment reports on behalf of Mondi Forests, and unpublished results

from other burning experiments conducted by C. de Ronde).

12.3.3 Assessment of Range Condition for Prescribed Burning in Grassland and Savanna

The necessity for rangeland to be burned or not depends upon its ecological status and physical condition. Generally, the condition of the grass sward determines whether rangeland should be considered for burning, as this component of the vegetation reflects the ecological status of the ecosystem and the presence of or its ability to produce adequate grass fuel to carry and support a fire.

Quantitative techniques have been developed to assess the condition of the grass sward in relation to prescribed burning. The first technique involves determining the condition of the grass sward in terms of its botanical composition, ecological status and basal cover and involves classifying the different grass species into different ecological categories according to their reaction to a grazing gradient, i.e. from high to low grazing intensities, as follows:

- *Decreaser species*
Grass and herbaceous species which decrease when rangeland is under or over-grazed.
- *Increaser I species*
Grass and herbaceous species which increase when rangeland is under-grazed.
- *Increaser II species*
Grass and herbaceous species which increase when rangeland is over-grazed.

12.2



Simplified techniques, based on the key grass species that have a highly significant effect on the potential of the grass sward to produce grass fuel, have been developed in southern and east Africa (Trollope, 1983; Trollope & Potgieter, 1986; Trollope & Trollope, 1999; Trollope et al., 2000). Using these techniques, criteria have been developed and successfully used to decide whether rangeland in a particular condition should be considered for burning or not.

The second technique involves estimating the grass fuel load using the Disc Pasture Meter developed by Bransby and Tainton (1977) and illustrated in Figure 12.2.

This technique involves relating the settling height of an aluminium disc dropped onto the grass sward to the standing crop of grass holding

up the disc, expressed in kilograms per hectare. There is a simple relationship between the settling height and the standing crop of grass, based on the fact that the more grass there is the higher off the ground the disc settles. This instrument has been successfully calibrated for much of the grasslands and savannas in southern and east Africa and research and field experience indicates that the calibration developed in the Kruger National Park (Trollope & Potgieter, 1986) in South Africa can be used as a general calibration for estimating grass fuel loads for management purposes in these regions of Africa (Trollope et al., 2000).

The calibration equation is:

$$y = -3019 + 2260 \sqrt{x}$$

where:

y = mean fuel load – kg/ha;

x = mean disc height of 100 readings – cm

The physical relationship between mean disc height and the mean grass fuel load described by this calibration equation is presented in Table 12.1.

The criteria that can be used to objectively decide whether rangeland needs to be burnt or not when grazed by domestic livestock, are that prescribed burning should not be applied if the grass sward is in a pioneer condition dominated by Increaser II grass species, caused by over-grazing. Burning is generally not recommended when rangeland is in this condition, in order to enable it to develop to a more productive stage, dominated by Decreaser grass species. Conversely, when the grass sward is in an under-grazed

Figure 12.2. The Disc Pasture Meter developed by Bransby and Tainton (1977) used to estimate the standing crop of herbaceous plant material in a grass sward.

condition dominated by Increaser I species, it needs to be burned to increase the better fire adapted and more productive Decreaser grass species. Finally, controlled burning is necessary when the grass sward has become overgrown and moribund as a result of excessive self-shading. These conditions develop when the standing crop of grass is generally > 4000 kg/ha and can be estimated with the Disc Pasture Meter. The criteria used for deciding whether to burn to control or prevent the encroachment of undesirable plants involves the same ecological criteria describing the condition of the grass sward. However, the grass fuel loads required for prescribed burning will differ depending on the encroaching plant species. An example of the form used to interpret the results of the range assessment technique based on key grass species and the estimates of the grass fuel load using the Disc Pasture Meter, is presented in Table 12.2. As mentioned previously, similar simplified techniques have been developed in the Eastern Cape Province and Kruger National Park in South Africa (Willis & Trollope, 1987; Trollope, Potgieter & Zambatis, 1989), in the East Caprivi region of north-eastern Namibia (Trollope, Hines & Trollope, 2000) and the central highlands of Kenya (Trollope & Trollope, 1999).

The following conclusions can be drawn from the results of the key grass species technique and the Disc Pasture Meter presented in Table 12.2.

Forage and fuel potentials

The range in the forage and fuel scores from very high (> 500) to very low (< 200) reflect the potential of the grass sward to produce forage for

grazing domestic livestock and wild ungulates and to produce grass fuel to support a high intensity grass fire. These categories have proven to be ecologically meaningful with highly applicable and practical management implications.

Trend

This refers to whether the rangeland is being moderately grazed, under-grazed, selectively grazed or over-grazed. The criteria used for deciding the intensity of grazing are: if the rangeland is dominated by Decreaser grass species, then it is being moderately grazed. If it is dominated by Increaser I grass species, then it is being under-grazed; if it is dominated by Increaser II grass species, then it is being over-grazed; finally, if the rangeland is dominated by both Increaser I and Increaser II grass species, it is being selectively grazed.

Soil erosion

The effect of the herbaceous vegetation on soil erosion depends upon the basal and canopy cover of the grass sward. If the basal and canopy covers are high, then the potential for soil erosion is low, and vice versa. Simple indices have been identified for these two parameters. Basal cover is satisfactorily described by recording the distance from a measuring point to the edge of the nearest grass tuft and is easily measured in the field. The different categories of point to tuft distance reflecting low (< 10 cm), moderate (10–20 cm) and high (> 20 cm) potentials for soil erosion were derived from data obtained from studies conducted in the East Caprivi region of Namibia. The standing crop of grass is an excellent index of

Table 12.1. Calibration for the Disc Pasture Meter developed in the Kruger National Park in South Africa and recommended for use in estimating the grass fuel load in African grasslands and savannas for management purposes (Trollope & Potgieter, 1986).

X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Cm	Kg/ha	cm	kg/ha	cm	kg/ha	cm	kg/ha	Cm	kg/ha	cm	kg/ha	cm	kg/ha	cm	kg/ha
2.0	177	6.0	2517	10.0	4128	14.0	5437	18.0	6569	22.0	7581	26.0	8505	30.0	9360
2.1	256	6.1	2563	10.1	4163	14.1	5467	18.1	6596	22.1	7605	26.1	8527	30.1	9380
2.2	333	6.2	2608	10.2	4199	14.2	5497	18.2	6622	22.2	7629	26.2	8549	30.2	9401
2.3	408	6.3	2654	10.3	4234	14.3	5527	18.3	6649	22.3	7653	26.3	8571	30.3	9421
2.4	482	6.4	2698	10.4	4269	14.4	5557	18.4	6675	22.4	7677	26.4	8593	30.4	9442
2.5	554	6.5	2743	10.5	4304	14.5	5587	18.5	6702	22.5	7701	26.5	8615	30.5	9462
2.6	625	6.6	2787	10.6	4339	14.6	5616	18.6	6728	22.6	7725	26.6	8637	30.6	9483
2.7	695	6.7	2831	10.7	4374	14.7	5646	18.7	6754	22.7	7749	26.7	8659	30.7	9503
2.8	763	6.8	2874	10.8	4408	14.8	5675	18.8	6780	22.8	7772	26.8	8681	30.8	9523
2.9	830	6.9	2918	10.9	4442	14.9	5705	18.9	6806	22.9	7796	26.9	8703	30.9	9544
3.0	895	7.0	2960	11.0	4477	15.0	5734	19.0	6832	23.0	7820	27.0	8724	31.0	9564
3.1	960	7.1	3003	11.1	4511	15.1	5763	19.1	6858	23.1	7843	27.1	8746	31.1	9584
3.2	1024	7.2	3045	11.2	4544	15.2	5792	19.2	6884	23.2	7867	27.2	8768	31.2	9605
3.3	1086	7.3	3087	11.3	4578	15.3	5821	19.3	6910	23.3	7890	27.3	8789	31.3	9625
3.4	1148	7.4	3129	11.4	4612	15.4	5850	19.4	6935	23.4	7913	27.4	8811	31.4	9645
3.5	1209	7.5	3170	11.5	4645	15.5	5879	19.5	6961	23.5	7937	27.5	8833	31.5	9665
3.6	1269	7.6	3211	11.6	4678	15.6	5907	19.6	6986	23.6	7960	27.6	8854	31.6	9685
3.7	1328	7.7	3252	11.7	4711	15.7	5936	19.7	7012	23.7	7983	27.7	8876		
3.8	1387	7.8	3293	11.8	4744	15.8	5964	19.8	7037	23.8	8006	27.8	8897		
3.9	1444	7.9	3333	11.9	4777	15.9	5993	19.9	7063	23.9	8030	27.9	8918		
4.0	1501	8.0	3373	12.0	4810	16.0	6021	20.0	7088	24.0	8053	28.0	8940		
4.1	1557	8.1	3413	12.1	4842	16.1	6049	20.1	7113	24.1	8076	28.1	8961		
4.2	1613	8.2	3453	12.2	4875	16.2	6077	20.2	7138	24.2	8099	28.2	8982		
4.3	1667	8.3	3492	12.3	4907	16.3	6105	20.3	7164	24.3	8122	28.3	9004		
4.4	1722	8.4	3531	12.4	4939	16.4	6133	20.4	7189	24.4	8145	28.4	9025		
4.5	1775	8.5	3570	12.5	4971	16.5	6161	20.5	7214	24.5	8167	28.5	9046		
4.6	1828	8.6	3609	12.6	5003	16.6	6189	20.6	7239	24.6	8190	28.6	9067		
4.7	1881	8.7	3647	12.7	5035	16.7	6217	20.7	7263	24.7	8213	28.7	9088		
4.8	1932	8.8	3685	12.8	5067	16.8	6244	20.8	7288	24.8	8236	28.8	9109		
4.9	1984	8.9	3723	12.9	5098	16.9	6272	20.9	7313	24.9	8258	28.9	9130		
5.0	2035	9.0	3761	13.0	5130	17.0	6299	21.0	7338	25.0	8281	29.0	9151		
5.1	2085	9.1	3799	13.1	5161	17.1	6327	21.1	7362	25.1	8304	29.1	9172		
5.2	2135	9.2	3836	13.2	5192	17.2	6354	21.2	7387	25.2	8326	29.2	9193		
5.3	2184	9.3	3873	13.3	5223	17.3	6381	21.3	7411	25.3	8349	29.3	9214		
5.4	2233	9.4	3910	13.4	5254	17.4	6408	21.4	7436	25.4	8371	29.4	9235		
5.5	2281	9.5	3947	13.5	5285	17.5	6435	21.5	7460	25.5	8393	29.5	9256		
5.6	2329	9.6	3983	13.6	5315	17.6	6462	21.6	7485	25.6	8416	29.6	9277		
5.7	2377	9.7	4020	13.7	5346	17.7	6489	21.7	7509	25.7	8438	29.7	9297		
5.8	2424	9.8	4056	13.8	5377	17.8	6516	21.8	7533	25.8	8460	29.8	9318		
5.9	2471	9.9	4092	13.9	5407	17.9	6543	21.9	7557	25.9	8483	29.9	9339		

Table 12.2. Key grass species technique for assessing the condition of the grass sward for prescribed burning in the East Caprivi region of Namibia.

ASSESSMENT RANGE CONDITION – GRASS SWARD

East Caprivi – Namibia

Land Type: Sample Site: Date:

Soil Type: GPS:

Category	Species	Frequency %	Forage factor	Forage score	Fuel Factor	Fuel score
Decreaser species:	<i>Brachiaria nigropedata</i>		7		8	
	<i>Digitaria-perennials</i>		5		3	
	<i>Panicum coloratum</i>		8		7	
	<i>Panicum maximum</i>		8		4	
	<i>Themeda triandra</i>		8		6	
Decreaser total						
Increaser I species:	<i>Aristida pilgeri</i>		-1		3	
	<i>Aristida stipitata</i>		-2		1	
	<i>Brachiaria dura</i>		4		3	
	<i>Eragrostis pallens</i>		0		6	
	<i>Tristachya superba</i>		-1		7	
	<i>Vetivera nigritana</i>		2		7	
Increaser I total						
Increaser II species:	<i>Annual Grass Species</i>		-2		-4	
	<i>Annual Aristida Species</i>		-1		-2	
	<i>Cynodon dactylon</i>		3		-2	
	<i>Dactyloctenium giganteum</i>		-1		0	
	Forbs		-2		-4	
	Bare Ground		-2		-4	
				237		390
Increaser II total			Forage score		Fuel score	
Other species						
TOTAL						

[Table 12.2 – continued on following page]

[Table 12.2 – continued]

Conclusion

Forage / Fuel potential

Potential	Score	Forage ✓	Fuel
Very high	> 500		
High	401 – 50		
Medium	301 – 400		
Low	200 – 300		
Very low	< 200		

Soil erosion

Factor	Potential for erosion		
	Low	Moderate	High
Tuft distance	<10 cm	10-20 cm	>20 cm
Distance = cm			
Grass std crop	Low	High	
	>500 kg/ha	<500 kg/ha	
kg/ha =			
Overall erosion potential			

the canopy cover of the grass sward and is readily measured in the field with the Disc Pasture Meter. The different values that have been assigned to this parameter were subjectively determined based on field experience in East Caprivi.

Prescribed burning

As indicated previously, prescribed burning will be recommended if the assessment of range condition indicates that the grass sward is not in a pioneer condition dominated by Increaser II

Trend

Category	%	Grazing	✓
Decreaser spp.		Moderate	
Increaser I spp.		Under	
Increaser I spp.		Selective	
Increaser II spp.		Over	

Prescribed burning

Botanical composition	%	Burn	
		Yes	No
Decreaser species			
Increaser I species			
Increaser II species			
Fuel load – kg/ha			
Overall decision to burn			

grass species and the grass fuel load is > 4000 kg/ha.

12.3.4 Classifying Fuels in Industrial Plantations

The cycle of growth in even-aged industrial plantations can be divided in four stages, namely:

1. *Young stage* – before the tree crown canopies start suppressing natural vegetation and the original vegetation base still dominates fuel loading.

2. *Partly suppressed stage* – prior to forming a complete tree crown canopy cover, but tree crowns now produce a significant leaf fall and leaves with the natural vegetation fuels form a mixture of well-aerated, vertically distributed, fuel strata.
3. *Suppressed stage* – when the natural vegetation base is almost completely suppressed by dominating (mature) tree crowns and dense forest floor layers – containing mostly leaves, partly-decomposed and decomposed leave substances from the dominating tree crowns – have replaced the natural vegetation fuel base.
4. *Clearfelling stage* – where the main tree crop has been clearfelled, timber was exploited and the stand has not yet been replanted. Fuel loading will now form a mixture of the original forest floor, slash from the felled trees and some returning natural vegetation, the degree of which depends on the time past after felling.

Fuels also vary as a result of natural vegetation patterns, species planted, site productivity and silvicultural treatments such as weeding, pruning and thinning. In some areas, the fuel status can also differ significantly between plantations and even within plantation stands. As fuel appraisal is such an important pre-requisite to accurate fire behaviour prediction, fuel classification is thus an important preliminary task to be conducted, and must be attended to before prescribed burning is applied. The use of a fuel classification system and site-specific knowledge of the complexity and spatial distribution for fire behaviour prediction

as well as other fuel and fire management tasks, is thus an important issue in plantation management (De Ronde et al., 1990).

The following basic fuel classification is still valid for even-aged, southern African pine stands (De Ronde, 1980):

Class I (Fig. 12.3.)

- Found under closed crown canopies.
- Dominated by continuous needle or litter layer with no living forest floor vegetation.
- Has a uniform (down) litter layer, normally less than 15 cm thick.
- Fuel loading exceeding 18 tons/ha.
- Has no flare-up potential
- Prescribed fire easy and safe to apply, without flaring.

Class II (Figure 12.4)

- Found mostly under closed crown canopies.
- Needle or litter layer with only low profile fuel suspension, with very little living forest vegetation, if any.
- Very little flare-up potential, if any, and a low profile.
- Litter layer as for class I, but suspended vertically up to 30 cm in places.
- Litter loading normally 10–18 tons/ha.
- When burning, some caution is required.

Class III (Figure 12.5)

- Found under crown canopies that are mostly touching, but with open gaps.
- Fuel suspension common up to 100 cm.
- Fuel loading variable.
- Forest floor vegetation patchy and variable.

12.3



- Flare-ups common.
- Caution required, and in most cases will have to revert to back-burning only

Class IV (Figure 12.6)

- Mostly found under partly closed to open crown canopies.
- Fuel suspension common, but mostly low profile.
- Fuel loading variable.
- Forest floor vegetation common, with high percentage dead material.
- Flare-ups common, low profile, but high in intensity.
- Prescribed burning not recommended, and can only be applied with extreme caution if really necessary at all.

Class V (Figure 12.7)

- Mostly found in older stands, which never closed crown canopies.
- Fuel suspension common up to 5 m.
- Fuel loading exceeding 18 tons/ha.
- Forest floor vegetation continuous and old, with high percentage dead material.
- Cannot be prescribed burned without serious damage to trees or mortality.

Figure 12.3. Example of a Class I fuel. Note absence of forest floor vegetation and low litter fuel profile (Photo: C. de Ronde).

Figure 12.4. Example of Class II fuel. Common low profile fuel suspension in the form of (mainly) pine needles is clearly visible (Photo: C. de Ronde).

12.4



12.3.5 Using Photo Series

This management technique for “fuel status evaluation” and prescribed burning application can be very useful, but has so far not been implemented at a significant scale in Africa south of the Sahara. However, its use (particularly if computer-based) is strongly recommended. Photo series can be used for natural fuels such as fynbos and grassland, as well as for even-aged industrial plantations.

The method used is to identify representative fuel situations for a particular region, and then to collect all fuel inventory data from these sites. Fuel structure, loading, depth and species composition must then be calculated, and this data must be provided on a single page at the bottom of a coloured photograph taken from the sampling site, together with all relevant supplementary information, such as recommended fuel management and prescribed burning. A single set of 20–40 plots/photographs should be sufficient for one region.

12.3.6 Predicting Crown Scorch Height in Industrial Plantations

Crown scorch is often used as the primary indicator of burning success (De Ronde, 1982). Scorch



is a function of the amount of heat that reaches the crown canopy. It is dependent upon fire intensity, understorey density (reflected in flame length), the distance to the base of the tree crown, crown intensity, ambient temperature and wind speed (De Ronde et al., 1990). McArthur (1971) graphed the relationship between fireline intensity, scorch height and flame height for *Pinus elliottii* and *Pinus caribaea* in Fiji, which was later used with actual scorch data recorded in South Africa to arrive at a flame height/scorch height relationship (De Ronde et al., 1990). The simplest way in which to predict crown scorch height is by multiplying the flame height by six. More accurate crown scorch height predictions are possible using the following formula:

$$(\text{Flame height}) \times 6 \times (\text{Wind correction factor}) \times (\text{Temperature correction factor})$$

Table 12.3 and Table 12.4 can be used for this calculation.

To calculate the probability of tree crown scorch before prescribed burning is applied – and if so, the degree of scorch height that can be expected – the following procedure should be followed:



- Estimate the predicted flame height that is expected (A), by either making use of BehavePlus (Andrews & Bevins, 2000) predictions, or by making use of other known formulas, or (if this is not possible), using expected flame heights such as 0.5, 1.0 and 1.5m, and predict scorch heights for each one of them.
- Approximate the height of the lowest living branches in the crowns of the trees (B).
- Multiply the predicted flame height (A) by six, which will then be the unadjusted scorch height (C).
- Multiply the unadjusted scorch height (C) with the scorch height correction factor for wind speed (D) and air temperature scorch height correction factor (E) to give the adjusted scorch height (F).

Figure 12.5. Example of Class III fuel, with backing fire being applied to avoid crown scorch from flare-ups (Photo: C. de Ronde).

Figure 12.6. Example of Class IV fuel. Note abundance of dead *Watsonia* leaves and open tree crown canopy, allowing direct sun and wind exposure (Photo: C. de Ronde).

Figure 12.7. Example of Class V fuel (Photo: C. de Ronde).

Table 12.3. Scorch height correction factor for wind speed.

Flame height(m)	Windspeed (km/h) at ca. 6 m above the forest floor						
	0	2.5	5.0	7.5	10.0	12.5	15.0
0.25	-	0.83	0.67	*	*	*	*
0.50	-	0.92	0.83	0.75	0.67	0.58	0.50
0.75	-	0.94	0.89	0.78	0.67	0.58	0.50
1.00	-	0.94	0.89	0.78	0.67	0.58	0.50
1.50	-	0.94	0.89	0.81	0.72	0.61	0.50
2.00	-	0.96	0.92	0.83	0.75	0.67	0.60
2.50	-	0.98	0.97	0.92	0.87	0.81	0.80
3.00	-	0.99	0.98	0.96	0.94	0.88	0.80

* Unreliable data

- If the adjusted scorch height correction factor (F) is lower than the height of the lowest living tree branches (B), the difference between the two will be the *safety margin* (G), and if (F) is more than (B), the difference between the two will be the height the scorch will reach into the tree crowns, or the *scorch height deficit* (H).

The greater the value of (G), the safer it will be to burn and the lesser chance that crown scorch will be experienced when prescribed burning is applied. Any degree of (H) will probably result in crown scorch if burning is applied, unless the average flame height can be lowered (e.g. by applying only the back-burning technique). The more the value of (H) is, the higher will be the degree of crown scorch that can be expected, and the relationship between (H) and the total height of

the living crown can provide *expected average percentage crown scorch*.

12.4 TRACER BELT PREPARATION

12.4.1 Using Natural and Unnatural Fuel Breaks and Topography

Tracer belts can be described as “burned” or “fuel-free” strips on both sides of a fire break – which have to be burned at a later stage before the fire season – prepared prior to the time the remainder of the fire break is applied to allow safe burning application. Where natural fuel breaks are incorporated into fire protection systems, these belts normally provide a more effective fuel break, and costs are also saved on tracer belt and fire break preparation costs.

Typical natural fuel breaks that can be used for this purpose are:

Table 12.4. Scorch height correction factor for air temperature

Air temperature (°C)	Scorch height correction factor
8 – 11	0.6
12 – 15	0.7
16 – 20	0.8
21 – 24	0.9
25 – 28	1.0
29 – 32	1.1
33 – 36	1.2

- Evergreen indigenous forests (with closed crown canopies, the provision being that they are free of continuous burnable fuel layers).
- Rivers with riverine forests on both riversides (also with no continuous burnable fuel layers).
- Swamps and wetlands (the latter with no burnable fuel, or burned fuel before the fire season).
- Rock sheets, rocky outcrops or areas with shallow soil and/or steep slopes, where no continuous burnable fuels (such as grasses) are found.
- Intensively grazed grasslands, where grazing has been applied to such a degree that the grass will not even burn properly under extreme weather conditions (examples of this can be found in certain African rural areas, particular where overgrazing and/or long droughty periods have been experienced and even semi-deserts have been formed).

Typical “unnatural” fuel breaks include:

- Public, agricultural or plantation roads acting as the base of fire protection lines, which can be strengthened by a single tracer belt on the road shoulder(s) to be widened and be more effective in this way. However, public roads can also form a serious fire hazard, requiring added fire break strengthening along both road sides.
- Power lines underneath which some form of fuel management is applied regularly (normally at the power suppliers’ expense).
- Railway lines with fire breaks on both sides of the railway track (in most cases provided by the railway company). Railway lines where steam locomotives are used can unfortunately also present increased fire hazard, requiring additional fire break protection.
- Ploughed lands present no fire hazard and these lands need no fire protection either.
- Vineyards are also fuel-free in most cases,

presenting no fire threat. However, heat from outside fires can damage vines easily through scorch.

- Mealie (maize) or other grain lands can most times be regarded as “unburnable”, but there is a certain (short) period after harvesting during which remaining (by now dead) upright plants can carry a fire in windy, dry conditions. These conditions are rare, but when they occur, can present a fuel base for very high fire intensities.

The following fuel-free areas can normally also be incorporated into fire protection systems:

- Areas where prescribed burning has been applied recently.
- Recent wildfire areas.
- Timber depots, industrial and build-up sites (provided surrounding areas are clean and fuel-free).

Topography must also be used correctly when tracer belts are prepared, as tracer belts situated on steep slopes can easily give rise to the formation of “erosion channels”, and may also be difficult to maintain in the case of rotation burning programmes.

On the other hand, tracer belts that follow topographical lines can be used to advantage to contain controlled fires, while those that follow lines against the topography will be difficult to safeguard during prescribed burning application. However, care must be taken not to make tracer routes too long, as will be pointed out in the next paragraph.

12.4.2 Deciding on Tracer Belt Routes

The preparation of tracer belts is a costly operation, but needs to be done thoroughly to provide safe fire break burning conditions. They normally have to be prepared before grassland (or fynbos) burning is applied, but are seldom required when burning inside industrial plantation stands, because these areas normally have a network of clean (fuel-free) compartment boundaries and roads that can act as tracers. Deciding where the fire breaks will be placed in the landscape will also determine where the tracer belts should be, and this is an extremely important decision-making process, already dealt with in Chapter 9. There are, however, some aspects that need careful consideration when the tracer belt preparation programme commences, not mentioned in Chapter 9. They are:

- Preparation of tracer belts near sensitive indigenous forest edges. These tracers should be at least 50 m away from the forest edge, to allow free natural regeneration development within these critical buffers. They must also be placed in the landscape in such a way that it will be possible to apply the fire so that the fire front will burn away from the forest edge, and not burn into these sensitive areas. The same precautions also apply to riverine forests.
- Avoid tracer belts on steep slopes and rather follow the natural topography where possible to avoid erosion, and not to create “erosion channels”.
- Rather incorporate “plantation islands” into grassland areas, than prepare tracer belts/

fire breaks around them at high cost.

- Prepare fire breaks right up to existing roads, so that only one tracer belt is required on each side of the road, and in that way a complete break-road-break system is prepared.
- Ensure that tracer belts are placed well away from sensitive areas such as heritage areas, breeding areas of rare bird species, caves and tourist walking trails. In the case of the latter, it may sometimes be convenient to use a foot-path as one tracer line, and then to burn only the one side of such a trail-path, if possible, for aesthetic purposes.
- Where possible, tracer belt routes should follow outstanding topographical features of the landscape. However, if following the contours of the land will make these lines too long, the placement of strategic cut-off lines should be considered. Man-made features, such as roads, power lines and railways, can also necessitate deviation from this approach.
- The golden rule is to remember that tracer belts have to be cost-effective.

12.4.3 Methods of Tracer Belt Preparation

In fynbos, vegetation slashing of tracer lines is the most commonly used method of tracer belt preparation, as the cutting down of the material close to the ground is the easiest way to remove standing fuel material. The cut material is then added to the side of the tracer belt that has to be burned, to provide additional fuel along these ignition lines. The roughness of the terrain, and steep slopes where the fynbos is normally situated (particularly at high altitude), do not allow any other method to be used effectively.

In grassland it is more a matter of creating adequate burnable material within the so-called “wet season” (before grassland curing), to allow tracer lines to be burned. Before the curing of grassland commences, there is normally no sufficient available fuel for tracer belts to be burned, and for that reason chemicals (herbicides) have to be applied within tracer belts first to kill the living grass, before these lines can be burned. Preparation of these lines has to be completed before curing commences, as tracer belts have to be in place before the (normally restricted) burning season after grassland curing, before the dry winter (fire) season.

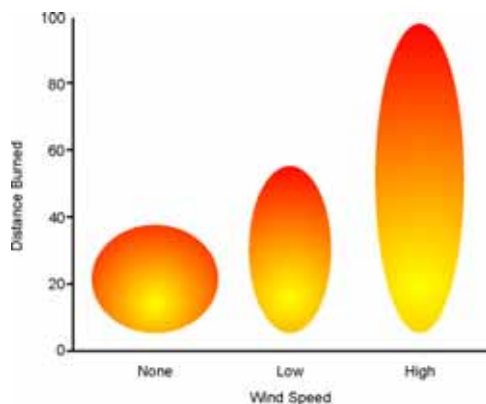
Sometimes slashing or mowing of tracer lines outside the grassland fire breaks is sufficient, particularly when older grassland has to be burned (normally during the wet season, before grassland curing), which has an adequate percentage dead grassland fuel to carry a fire before curing sets in. In this case it is normally dry biomass carried forward from previous curing season(s), during a year (or years) when fire was excluded. Where the terrain is uniform, with few slopes, ploughing of tracer belts can also be used, provided no rocks are found along these lines.

12.5 WEATHER AND TOPOGRAPHICAL CONSIDERATIONS

12.5.1 Using Weather and FDR Forecasts

Knowledge of weather is the key to successful burning! Given adequate fuel, it is both past and current weather that determines if and how a fire will burn. Wind, relative humidity, temperature and precipitation are the more important elements

12.8



to consider. These factors all influence fuel moisture which, as mentioned in Chapters 3 and 4, is the single most critical factor in determining fire behaviour. Good prescribed burning conditions may exist for only a short period of time (hours or days), so their impending arrival needs to be recognised as soon as possible to fully utilise them.

If you contemplate using prescription fire, it is mandatory for you to become familiar with local weather patterns that are favourable for prescribed burning as well as local “watchout” situations. Before igniting a fire, always obtain the latest weather forecast for the day of the burn and the following night. When possible, get a two to four day weather outlook (De Ronde et al., 1990).

It is essential for a prescribed burning operation to be completed during periods of stable weather, and suitable relative humidity, wind and temperature. It is not desirable to burn when a weather front is passing through the target area because wind direction and wind speed shift rapidly, as do temperature and relative humidity.

Wind is the most important factor directly influencing fire behaviour, even a slight increase

in wind speed can, for example, cause fire intensity to double or triple. Wind speed generally increases after daybreak, reaching a maximum in the early afternoon, and then decreases to a minimum after sunset. Sudden changes in wind direction can also be extremely dangerous when prescribed burning is applied, and if these are predicted, burning should be avoided. Should a change in wind direction still be experienced, immediate action in the form of concluding (“closing up”) the burn will be required to avoid the fire from becoming uncontrolled, particularly if this coincides with an increase in wind speed.

Wind characteristics are crucial. A steady wind blowing from a favourable direction within the range of 0 to 15 km/h (mid-flame wind speed) is recommended for most prescribed burns. Wind direction and wind speed influence the size and shape of the burn (Figure 12.8).

Generally, the greater the wind speed the more elongated is the burn. Relative humidity, air temperature and wind speed all have reasonably predictable diurnal cycles within local climates and topographies. The more extreme weather conditions of very low relative humidity and high winds are not recommended for standard prescribed burning.

Air relative humidity and air temperature should also be monitored carefully, particularly if a cold front has been predicted to pass through the area identified for burning. In most cases, burning should be avoided when this has been predicted for the day to be burned to avoid unstable weather conditions normally accompanying these conditions. In natural fuels, such as grassland, fire will ignite between 0 and 65% relative

Figure 12.8. The relative distance burned under three different wind speeds following single point ignition.

Table 12.5. Relationship between relative humidity and ignition of various fuel types.

Relative Humidity	Comments
>65%	No ignition
50–65%	Burns grass only
25–45%	Burns woody and grass fuels safely
5–20%	Woody fuels produce firebrands

humidity (RH) (Table 12.5). Ignition is rather tentative between 60 and 65% RH and it is very dangerous to ignite a fire at <15% RH because of the difficulties of fire suppression should the fire escape.

The most common range of ignition during prescribed burning is 20 to 50% RH and air temperatures of 10 to 30°C.

Relative humidity, temperature and wind speed all have reasonably predictable diurnal cycles within local climates and topographies. To illustrate this, hourly relative humidity and air temperature profiles for Pilanesberg National Park for 1987 are used. Relative humidity was highest early in the morning (at the time of minimum temperature) and began to decline during the morning as the air temperature increased, and the wind speed also tended to increase. As the temperature reached its maximum in mid-afternoon, the RH reaches its daily low and the wind speed generally peaked. These RH and temperature profiles also illustrate how there is greater range in air temperature in winter (e.g. May–July 1987), than in spring or in early summer (September–October 1987).

Rainfall has a pronounced effect on both fuel moisture and soil moisture. It is thus also important to have a good estimate of the rain falling on an area to be burned for a few weeks prior to planned ignition. Rainfall amounts are fairly uniform with some large weather systems but they vary widely with others. Shower activity and amount is notoriously difficult to predict, even for nearby sites. The only reliable method to determine the amount of precipitation that actually falls on a site, is to place an inexpensive rain gauge on the area.

If a fire danger rating prediction (FDR) system is operational in your region, make full use of these predictions and, depending on where the available ratings are applicable, apply them in the area to be burned, in tandem with the actual (latest) weather forecasts.

12.5.2 On-The-Spot Weather Monitoring

Weather observations should always be taken at a prescribed burn site prior to, during and immediately after the fire. Such observations are important because they serve as a check on the weather forecast and keep the burning crew up

to date on any local influences or changes. Precipitation amount in particular can vary widely between locations. Measurements taken in an open area, on a forest road and in an adjacent stand are likely to be considerably different. Weather readings during a fire should be taken in a similar fuel type upwind of the burn to avoid heating and drying effects of the fire. Readings should be taken and recorded at one to two-hour intervals during a fire and whenever a change in fire behaviour is noticed. By taking periodic readings and observing cloud conditions, a competent observer can obtain a fairly complete picture of current and approaching weather. Inexpensive easy-to-use belt weather kits are available from forestry supply outlets in the USA and elsewhere (De Ronde et al., 1990).

There are limited conditions under which security fires/fire breaks should be lit, in order to reduce the risk of escape. When these burns are conducted in dynamic grassland, they are usually ignited early in the dry season when herbaceous vegetation may not be completely cured, under low wind and moderate relative humidity conditions when the burning index is moderate and when the rate of spread is low.

A spot weather forecast should be obtained from the weather bureau for the day before the burn (for 14:00), and the following day (24 hour forecast for 14:00), where no daily fire danger index information is provided, such as in most forestry regions of southern Africa. This forecast should be for: Stability of the existing weather system, maximum temperature, minimum relative humidity, wind speed and wind direction. Security burning is recommended under a moderate burning index,

a low to moderate rate of spread, moderate to high fine fuel loadings, wind speed below 15 km/h and within a relative humidity range of 15 to 60% (Bailey et al., 1993).

12.5.2 Considering Topography in the Application of Prescribed Burning

On level terrain, wind determines the direction of fire spread, although on-site wind direction may be influenced by nearby topographical features. When burning on even slopes, not considering the influence of wind, burning down slope will create backfiring conditions and burning uphill will create a headfire. The steeper the slope, the greater will be the contrast between these two fire conditions. Varying slope conditions and aspects within a particular area to be prescribed burned will need careful planning of burning application and techniques, and special burning methods – developed for this kind of terrain – may have to be applied.

Uniform slopes can be used to advantage when applying prescribed burning by first creating a safe fire strip and using the backing fire technique on the higher ground of the area, against which strip-head fire can be applied, until the whole area has been covered by fire. Uniform slopes are not suitable for circular firing or point source ignition.

12.6 PRESCRIBED BURNING TECHNIQUES

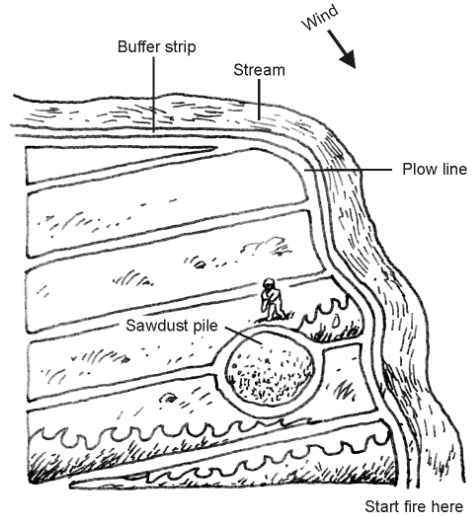
12.6.1 Back Firing

A fire must be started along a downwind baseline such as a road, a tracer belt or a plough line and allowed to back into the wind (or down-slope).

Variations in wind speed have little effect on the rate of spread of a fire burning against the wind. Where there is no slope, some wind is necessary to give the fire direction, but backing fires do not seem to spread much faster than 1 m/min, no matter what the wind speed.

Back fire is the easiest and safest of prescribed fire methods to use, provided wind speed and wind direction are steady. Once the fire backs away from the control line, escape is unlikely, resulting in less worry about damage to adjacent stands. Because crown scorch is minimised in even-aged plantation stands when backing fires are used, this technique lends itself to use in heavy fuels in industrial timber plantations. In most plantation fuels, such as in pine stands, the initial fire should be a back fire. It should, however, not be used in overgrazed grassland, where a continuous head fire line is required to ensure a total burn cover. A major disadvantage of this burning technique is the slow rate of fire spread. When a large area has to be burned, it must often be divided up into smaller blocks with interior plough lines or tracer belts. These blocks must be ignited simultaneously to complete the burning operation in a timely manner (De Ronde et al., 1990).

Back fires can be used as a starting line in fynbos and in grassland vegetation with varying topography, as well as when applying prescribed fire in industrial plantations.



should not be used when prescribed burning is applied inside plantation stands, as the high intensity of the fire can give rise to damaging crown scorch where the fire fronts converge.

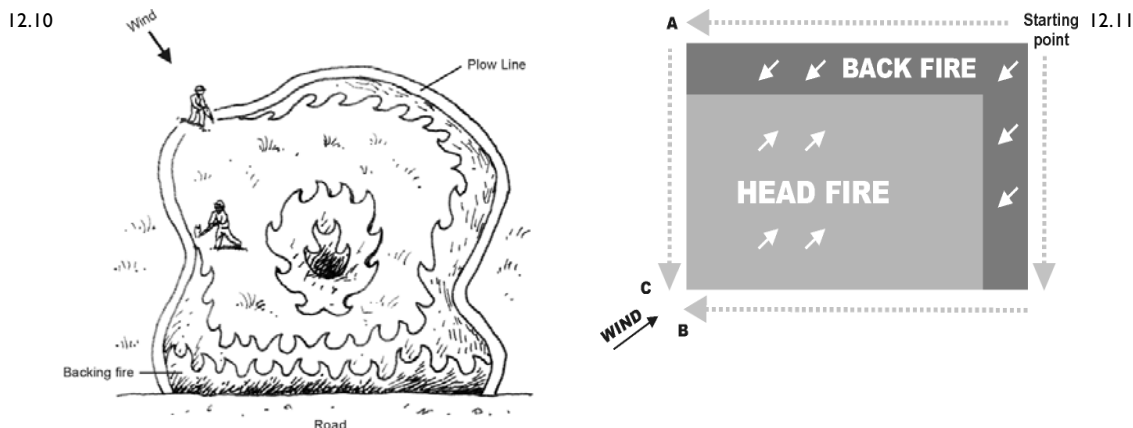
As with other burning techniques, the down-wind control line is the first line to be ignited. Once the baseline is secured, the entire perimeter of the area is ignited so that the flame fronts will all come together towards the centre of the plot. One or more spot fires (centre fires) are often ignited in the centre of the area and allowed to develop before the perimeter of the block is ignited. The convection generated by these interior fires creates in-drafts that help pull the outer circle of fire toward the centre, thereby reducing the threat of "slop-overs" and heat damage to adjacent stands.

Under unstable atmospheric conditions, the fire may develop a strong convection column and burning materials can be lifted aloft in this column if

12.6.2 Centre and Circular Firing

This technique is useful when burning harvested areas inside industrial plantations where a hot fire is desired to reduce logging debris and to kill unwanted vegetation prior to tree planting. It

Figure 12.9. Back fire technique (Wade et al., 1988, revised).



not completely consumed, and can cause spotting problems. Slash burns in plantations can also give rise to ground fires in humus pockets which can smoulder for weeks. Thorough wetting of the perimeters, as soon as possible after the fire is applied, is thus recommended to avoid this (De Ronde et al., 1990).

The procedure to be followed when burning a grassland area or camp is illustrated in Figure 12.11. Field procedure – illustrated in Figure 12.11 – comprises the following steps:

- Initiate simultaneously two surface back fires burning against the wind along two lines commencing at the starting point and proceeding to corners A and B of the camp. The resultant back fire will be a slow moving burn characterised by low flames and relatively easy to control.
- Allow the back fires to burn back until an adequate fire break has been established.
- Initiate a surface head fire burning with the

wind by proceeding from points A and B to point C simultaneously and as swiftly as possible. The resultant head fire will be a fast moving burn characterised by high flames that, on meeting the back fire, will cause both flaming fronts to assume a vertical angle, thereby preventing the fire from spreading further.

This method of applying a prescribed burn is the standard procedure that is used by field operators involved in extensive land management, and greatly reduces the risk of losing control of prescribed burns.

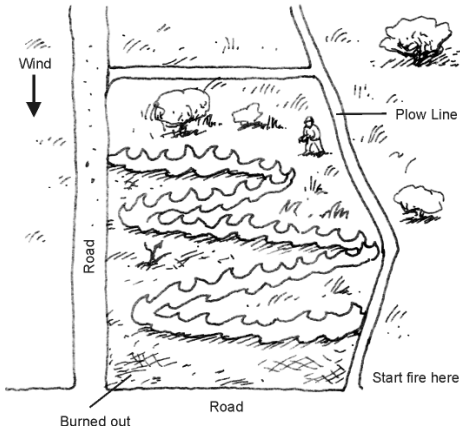
12.6.3 Strip Head Fire

In strip head firing, a series of lines are set progressively upwind of a fire break in such a manner that no individual line of fire can develop a high energy level before it reaches a fire break or another line of fire. A back fire should always be set first to secure the downwind base line and then the remainder of the area can be treated

Figure 12.10. Centre and circular firing application (Wade et al., 1988, revised),

Figure 12.11. The field procedure recommended when applying a prescribed burn in grassland.

12.12



with strip-heading fires. The distance between ignition lines is determined by the desired flame length, and the spacing between lines should change throughout a burn to adjust for slight changes in topography, stand density, weather or fuel.

A short distance between strips keeps an individual line of fire from gaining momentum, but is time-consuming and uses a lot of torch fuel. Furthermore, higher intensities occur whenever lines of fire burn together, increasing the likelihood of, for example, crown scorch in industrial plantations if applied there. This technique is commonly used when applying prescribed burning inside plantations, but can also be used when burning fynbos or grassland fuel, particularly if circular firing is producing a too high intensity.

Head fires are very sensitive to changes in wind speed (De Ronde et al., 1990). Only enough wind to give a heading fire direction (1–3 km/h inside plantation stands, or at mid-flame height in grassland or fynbos) is needed, because flame length (and thus also fire intensity) increases with

wind speed. Allowing a head fire to move across an entire block of fuel without stripping should only be done in areas with light loadings, and for that reason use of the technique is restricted in exposed fuels such as grassland or fynbos.

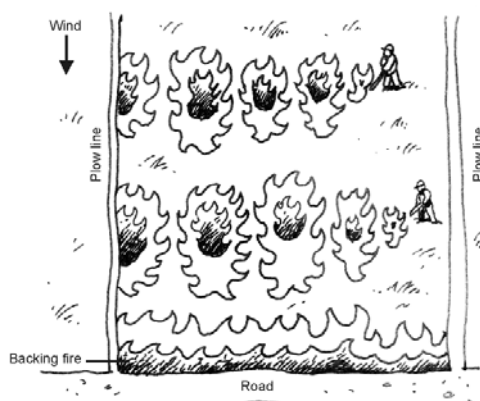
12.6.4 Point Source (Grid) Ignition

This technique is mostly used when prescribed burning even-aged, mature, plantation stands, classified as class I or class II fuels. When applying this technique, timing and spacing of the individual ignition spots are the keys to the successful application of this method. First, a line fire is ignited across the downwind edge of the block and then allowed to back burn into the block to increase the effective width of the control line. A line of spots is then ignited at some specified distance upwind of the backing fire and the process is continued until the whole block has been ignited.

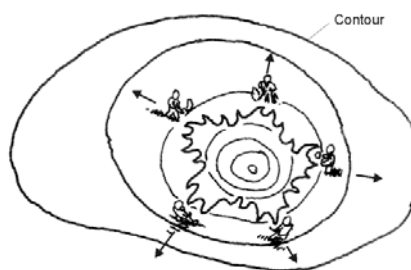
To minimise crown scorch, ignition-grid spacing is selected to allow the spots along a line to head into the rear of the spots along the downwind line before the flanks of the individual spots merge to form a continuous flame line. The merger of successive ignition lines thus takes place along a moving point, rather than along a whole line at the same time. Merging of spots can be ensured by using a square grid. Close spacing between lines helps the individual spots to develop, but ensures that the head of one spot will burn into the rear of the downwind spot before the heading fire's potential flame length and intensity are reached. Rectangular grids, with wider spacing between the lines than within a line, should not be used because such a pattern may allow the spots along a line to merge into a

Figure 12.12. Strip-head fire technique (Wade et al., 1988, revised).

12.13



12.14



line of heading fire before running into the rear of the downwind spots. Once the first few lines have been ignited and their fire behaviour assessed, intensity can be regulated to a certain degree by changing the time between ignition points within a line, the distance between points as well as the distance between lines. Fire intensity is decreased by widening the interval between ignition points along a line. If the fire intensity is still too high after doubling the interval while maintaining a 40 m distance between lines, firing should be halted.

When using point source fires, much of the area will be burned by heading and flank fires and very little by back fires. Thus, if conditions are ideal for "line-back fires", point source fires may get too intense. Preferred burning conditions include low (1–2 km/h), variable, wind speed inside stands (De Ronde et al., 1990).

12.6.5 Chevron Burning

This burning technique is suitable in broken, steep, topography, where a prominent round hill (or

"koppie") occurs in the area to be burned. Requirements include light or no wind conditions (the steep slope being the most prominent factor influencing fire behaviour), and five to six burners with drip torches.

Ignition is started simultaneously by all the burners on the top of the hill, and they then move in a star-like pattern downhill at equal speed, thus creating a backing fire/flank fire pattern. Progress is rather slow, but it is a very safe technique for this type of terrain, and can be applied in all kinds of fuel, grassland, fynbos and inside industrial plantations with this type of topographical terrain variation. Fire intensity can be controlled by moving the ignition lines faster or slower down the slopes.

12.6.6 Edge Burning

Edge burning is not a firing technique in the true sense of the term, but is applied for the same reasons that tracer belts are burned on the edges of grassland or fynbos fire breaks. Edge burning is applied to the edges of a plantation stand which

Figure 12.13. Point source (grid) ignition (Wade et al., 1988, revised).

Figure 12.14. Chevron burning procedure.

12.15



12.16



are to be prescribed burned at a later stage. Edges should be burned soon after rain as the edges of plantation stands dry out much faster than the slower-drying fuel inside the stands, and this so-called “black-lining” is simply the first part of a two-step burn designed to minimise damage along the edge of a plantation. Plantation edges normally burn with higher intensity because:

- Edges are more exposed to the influences of sun and wind, leading to more rapid drying of fuels.
- Increased sunlight on the edges stimulates the growth of understorey species such as bracken fern, which tends to cause fires to flare along these transition zones.

Fire behaviour on edges is directly exposed to wind, in contrast to the fuels under a plantation stand canopy, which experience a much-reduced wind speed.

12.6.7 Pile and Windrow Burning

This technique is commonly used in even-aged industrial plantations. Pile or windrow burning is

sometimes used to reduce slash loading levels after clearfelling and timber exploitation, but broadcast burning is preferred because (a) it is cheaper because of less handling of debris, and (b) the more even spread of fuel provides a lesser probability of site degradation (De Ronde & Zwolinski, 2000). However, sometimes windrows have been inherited because they were created for improved access, and have to be burned at a later stage for fuel management purposes.

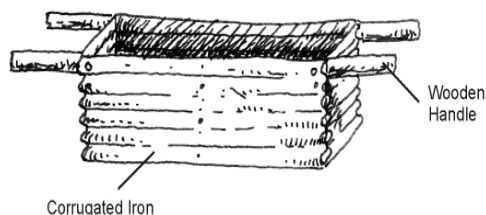
Techniques used to burn piled debris are somewhat fixed because of the character and placement of fuel. The upwind side of each pile should be ignited. Under light variable winds, the whole pile perimeter can be ignited (De Ronde et al., 1990).

When brush rows have been formed inside plantation stands to stack pruning and thinning material in stands to be prescribed burned, these can be burned under conditions which are still too moist for burning the remaining forest floor as a first-stage burn. The remainder of the area can be burned later, when further fuel drying will allow the latter to be ignited.

Figure 12.15. Application of an edge burn in a mature *Pinus patula* stand in the Tsitsikamma region of South Africa (Photo: J.G. Goldammer).

Figure 12.16. Slash burn on a clearcut of a *Pinus patula* stand in the Tsitsikamma region of South Africa (Photo: J.G. Goldammer).

12.17



12.6.8 “Botha fire-box” for Constructing Fire Breaks

A rather unusual method of burning fire breaks in grassland and savanna areas, is by making use of the “Botha fire-box” method. This comprises constructing an open box-like structure with four sheets of corrugated iron fitted with four wooden handles (Figure 12.17).

The grass material is set alight around the inside perimeter of the “box” causing a vortex of hot air to rise resulting in a hot, clean burn. At the completion of the burn the “box” is moved forward and the same process repeated. The advantages of this method are:

- It permits safe burning under extremely windy conditions.
- It is labour efficient.
- The fire-box is very easy and inexpensive to construct.
- It is well suited to broken topography as well as stony terrain.

The disadvantage of this method is that it is slow in comparison to the other burning techniques for constructing fire breaks, but this is offset by the greater degree of safety. It is also quicker

than manually constructed clean cultivated fire-breaks.

12.7 PRESCRIBED BURNING PLANS

12.7.1 Background

Planning a prescribed burn involves considerably more than just writing a burning plan. A successful prescribed fire is one that is executed safely and is confined to the planned area, burns with the desired intensity, accomplishes the prescribed treatment, and is compatible with resource management objectives. Such planning should be based on the following factors:

- Physical and biological characteristics of the site to be treated.
- Land and resource management objectives for the site to be treated.
- Known relationships between the pre-burn environmental factors, expected fire behaviour and probable fire effects.
- The existing art and science of applying fire to a site.
- Previous experience from similar treatments on similar sites (Fischer, 1978).
- In some cases, smoke impact from aesthetic, health and safety standpoints.

The first step to a prescription is a site-by-site (or stand-by-stand) evaluation. Determine the needs for each stand and what actions should be taken to meet these needs. In the case of industrial plantations, alternatives to prescribed fire should be considered and a decision reached regarding the preferred treatment. Well in advance

Figure 12.17. A “Botha fire-box” comprising four sheets of corrugated iron fitted with four wooden handles.

of the burning season (which also has to be selected correctly to maintain biodiversity in the case of grassland and fynbos), choose the sites/stands to be burned. Over-plan the number of hectares to be burned during the coming season by 10 to 20%, so substitutions can be made if necessary, and in this way additional areas can be burned if favourable weather continues. In many locations, the number of suitable burning days varies widely from year to year. Set burning priorities and specifically designate those burns, which require exacting weather conditions. Considerations include fuel characteristics, required fire intensity and fire residence time, scorch height restrictions (inside *Pinus* stands) and potential smoke problems in urban or industrial areas, or near public roads.

12.7.2 The Written Plan

The written burning plan should be prepared by a knowledgeable person prior to the burning season, to allow time for inter-functional coordination and any necessary arrangements for human resources, equipment, financing or other needs. Be ready to burn when prescribed weather occurs. Some plans will be short and simple, while others will be more complex. In an area where broad variations in topography and type and amount of fuel exist, developing an effective burning prescription is difficult, if not impossible. Where practical, it is better to divide such areas into several burn units and prepare a separate burning plan for each. Treatment constraints should be included in, or attached to, the plan. Fischer (1978) named the following:

- Environmental constraints (air quality, water quality, accelerated erosion).
- Multiple-use constraints (protection of other uses, resource management trade-offs).
- Economic constraints (maximum cost per unit area).
- Operational constraints (access, terrain, manpower).
- Administrative constraints (policy, rules, etc.).
- Legal constraints (fire laws, forest practice acts, etc.).

A prepared form with space for all needed information is best. The form will serve as checklist to ensure that nothing has been overlooked. A "simple" form that can be used on burns that are well within large landholdings that do not contain public roads, taken from Wade and Lunsford (1989), somewhat revised, is presented (Table 12.6).

12.7.2.1 Purpose and Objectives

List the reason for prescribing the fire (e.g. for fire protection or fuel reduction). In addition, give a specific quantifiable objective. State exactly what the fire is to do – what it should kill or consume, how much litter should be left (inside plantations), etc. Also concisely describe desired fire behaviour including rate of spread, flame length and fireline intensity. In case the prescribed weather conditions do not materialise, this description may provide some latitude so that firing techniques can be adjusted to accommodate the existing weather and still accomplish the objective(s).

Table 12.6. Simple prescribed burning unit plan

Landowner/Manager:	Purpose of burn:
Address:	Hectare to be burned:
Tel. No.:	Previous burning date:
Stand and fuel description (if burning inside <i>Pinus</i> stands)	Vegetation and fuel description (if burning grassland, fynbos or plantation slash after clearfelling)
Fuel class: Crown canopy closure class:	Standing fuel height and density description:
Understorey height and type:	Available (burnable) fuel type and amount:
Dead fuels, description and amount:	Status of curing required (in grassland):
Height to bottom of living crown:	
Predicted crown scorch height:	
% Crown scorch deficit/safety margin:	
Pre-burn factors:	
Manpower and equipment needs:	Tracer belts/fire belts required:
Burning technique(s) to be applied:	Adjacent landowners to notify:
Special precautions:	Smoke restrictions:
Estimated no. of hours to complete:	
Weather factors	Desired range
Surface wind (speed & dir.):	Predicted
Transport winds (speed & dir.):	Actual
Minimum relative humidity:	
Maximum temperature:	
Fine fuel moisture:	
Days since rain: Amount:	
Fire Behaviour	Desired range
Type of fire:	Actual
Best month to burn:	Date burned:
Flame length:	
Rate of spread:	
Cm of litter to leave (where applicable):	
Evaluation	Immediate
Any escapes?:	Hectare:
Objectives met:	
Burning cover:	
Technique used OK:	
Smoke problems:	
(in case of burning inside <i>Pinus</i> stands)	
% Crown scorch:	
% Understorey consumed:	
Remarks:	
Prescription made by:	Future
	Evaluation by:
	Date:
	Soil movement:
	Adverse effects:
	(in case of burning inside <i>Pinus</i> stands)
	Insect/disease damage:
	% Understorey kill:
	Tree damage:
	Remarks:
	Date:

12.7.2.2 Map of Burning Unit

A detailed map of each burning unit is an important part of the burning plan. The map should show boundaries of the planned burn, adjacent landowners, topography, control (or tracer) lines and other essential information.

12.7.2.3 Equipment and Personnel

List equipment and personnel needed on-site and on standby. Assign duties. In the case of burning in plantations, chain saws are useful additions to the equipment list, and in the case of fynbos burning, slashers.

12.7.2.4 Fire Prescription

In the case of burning inside plantation stands, include species involved, height to lower crown, predicted scorch height (with deficit or surplus), understorey type, density and composition. Where natural fuels are involved, status of the herbaceous layer, percentage curing, fuel depth and loading are all important. List the desired range of pertinent weather factors including eye-level wind speed and direction, relative humidity, temperature, fine-fuel moisture content, precipitation and drying days needed. Recommended burning technique(s), type of fire, desired rate of spread, fireline intensity, and estimated number of hours to complete the burn will also be required.

12.7.2.5 Estimated Number of

Available Burning Days

This will differ in fynbos, grassland or within industrial plantations, but in all cases it is important to identify the correct season of the year when burning should be applied, which may

differ from region to region. In many regions the climate is characterised by dry and rainy seasons, when it is most suitable to burn during the transition period between the wet and dry season. Local wind patterns, such as the bergwind in southern Africa, may significantly restrict the number of available burning days, particularly if this is linked to specific burning season recommendations for ecological goals.

12.7.2.6 Time of Day

As a general rule, plan burning operations so the entire job can be completed within a standard workday. Prescribed fires usually are ignited between 10:00 and 14:00. Some burners like to start early, as soon as the sun has evaporated any dew, and then switch firing techniques as conditions change during the day. When burning dangerous fuels inside plantation stands, or when burning slash after clearfelling, it is sometimes safer to start burning during the late afternoon or even after dark in the evening. When burning large blocks of fynbos in the mountains, burning may continue from the day into the night because the distance to be ignited is just too much to complete within normal working hours. Some sections of fynbos may also present too dangerous conditions during a late summer day, and cooler conditions may be preferred. The decision during what time of the day depends somewhat upon your knowledge of local weather and the reliability of the weather forecast.

12.7.2.7 Firing Plan

The firing plan should consist of a narrative section as well as a detailed map. A plantation stock map,

topographical map or vegetation age map are all ideal for this purpose because these maps already contain much pertinent information. The following should be added:

- Firing technique, ignition method (i.e. drip-torch), ignition pattern and planned ignition time.
- The planned distribution of manpower and equipment for setting, holding, patrolling and mopping up the fire.
- Location and number of reinforcements that can be quickly mobilised if the fire escapes.
- Instructions for all supervisory personnel, including complete description or illustration of assignment, and forces at their disposal.

12.7.2.8 Escaped-Fire Plan

Identify potential fire escapes and specify actions to take should such occur. Designate who will be in charge of suppression action and what personnel and equipment will be available.

12.7.2.9 Control and Mop-up

List the necessary safeguards to confine the fire to the planned area. Mop up promptly and completely. Guarding the control lines is particularly important in the case of plantations, slash and fynbos for up to 24 or 48 hours, depending on conditions. In the case of slash burning after clearfelling trees, it may be necessary to extend this period to one week or even more, depending on ground fore development after the initial burn.

Once the burning operation has been completed, *the crew is not disbanded until there has been a thorough check of the entire burn perimeter.*

The crews should wet down smouldering dung piles (in grasslands), old tree stumps or root channels (when burning slash or re-established tree stands), or any other smouldering objects or underground/above-ground source of fire. In natural savanna, white rhino dung middens ignited by firebrands across a road or track can smoulder later igniting the adjoining fuels.

12.7.2.10 Evaluation

A record of actual weather conditions, fire behaviour and the effects of the fire on the environment are essential. This information is used to determine the effectiveness of the burn and to set criteria for future burns. Just prior to igniting the burn, record wind speed and direction, relative humidity, temperature, fuel moisture, and soil and lower litter dampness (in the case of plantation burning). Continue to record weather conditions at two to three-hourly intervals throughout the burn, and also measure flame length and rate of spread during the burning operation, if possible. After completing the burn, check control lines, and record burning cover. Where patches have not been burned over by the fire, arrange re-ignition. In the case of prescribed burning inside even-aged stands, record the amount of crown scorch, consumption of understorey, litter and humus layers, and any other evidence of fire intensity, such as exposed mineral soil or cambium damage.

12.7.2.11 Pre-burning Planning in Grassland

It is important to inspect the area to be burned in the field. The fire boss should familiarise him or

herself with fuels and topography. When burning grassland, the following should be noted: (a) grass-fuel load, (b) degree of curing of the grass (green, partly cured, or dry grass) and (c) bush or scrub density and fuel load. If there is a large amount of scrub this is important as it adds to the fuel load. To assess the fuel load, a suitable technique should be used. Estimation techniques such as the dry weight rank (DWR) using a set of photographs (Francis, Van Dyne & Williams, 1979), or the weight-estimate method (Goebel, 1955), or indirect methods, e.g. the pasture disc meter (Trollope & Potgieter, 1986; Brockett, 1996) can also be used. A grassland fuel curing guide was developed for temperate cropping regions by the Country Fire Authority, Victoria, Australia*. The guide consists of photographs for a range of curing percentages. These are: 0%, 10%, 20%, 30%, 40%, 50–60%, 70–80%, 90% and 100%, and includes guidelines for each as to colour and seed.

Bush control burns are generally more challenging than other uses of prescribed burning. They require drier conditions, woody fuels that generate higher fireline intensity, and they may require higher wind speeds to enable adequate spread rates of the fire. These properties increase the potential for escape and for damage to the soil. High volumes of flaming and smouldering firebrands are usually a normal component of bush control burns. It is recommended that there be wider perimeter fuel breaks, a very experienced fire boss with hand-picked, experienced ignition and suppression crews, and sufficient fast, effective suppression equipment to put out any fire excursions beyond the burn perimeter.

12.7.3 Preparing for the Burn

Good preparation is the key to successful burning. It is essential to maximise net benefits at acceptable cost. Preparation consists of all steps necessary to make the area ready for burning and of having all needed tools and equipment in good operating order and ready to go.

12.7.3.1 Establishing Control Lines

- Construct lines in advance of burning, preferably after leaf fall in the case of prescribed burning inside plantation stands, under the trees. In the case of dynamic grassland, tracer lines should be created (and burned) before grassland curing.
- Hold constructed lines to a minimum, keeping them shallow and on the contour as much as possible. Consider igniting them from wetlines in the case of burning in plantations, or use a chemical retardant sprayed along the ground to serve as a temporary control line. Use access roads or existing footpaths where possible.
- Use natural barriers such as streams whenever possible.
- Keep control lines as straight as possible.
- Widen control lines at hazardous areas.

12.7.4 Executing the Burn

There are few days of good prescribed burning weather during the year, particularly in the case of fynbos block burning, and prescribed burning inside plantation stands with crown scorch probability. With adequate preparation, burning can begin without loss of opportunity. The burning crew should be well equipped with proper clothing and

* Guide is obtainable from Mark Garvey, CFA, PO Box 701, Mt Waverley, VICTORIA, 3149, Australia.

safety equipment, and should be in good physical shape. Good communication is also important during the burning operation, and plenty of drinking water should be on hand.

12.7.4.1 Checklist

- Make sure all equipment is in working order and safe to use.
- Notify adjoining property owners and local fire control organisations before starting the fire.
- Carry burning plans and maps to the job.
- Check all control lines and clear these of any burnable material.
- When burning inside plantations, check humus and soil dampness.
- Post signs on public roads and be prepared to control traffic should visibility become dangerously impaired.
- Check the weather before starting the burn and keep updated throughout the burn.
- Instruct the crew on procedures, including safety precautions and the proper operation of equipment and hand tools.
- Inform the crew of starting point and firing sequence.
- Have good portable communication equipment at hand, and test radios and cell phones before ignition.
- Test burn with a trial fire before firing.
- Burn so that wind will carry smoke away from sensitive areas.
- Be alert to changing conditions and be prepared to change burning techniques or put the fire out if an emergency arises.
- Mop up and patrol perimeters constantly until there is no further danger of fire escape.

12.7.5 Evaluating the Burn

The purposes of a burn evaluation are to determine how well the stated objectives of the burn were met and to gain information to be used in planning future burns. An initial evaluation should be made within a day or two after the burning was applied. A second evaluation may be made during or after the first post-fire growing season.

12.7.5.1 Points to be considered

- Were objectives met?
- Was the burning plan adhered to? Were changes documented?
- Were fuel conditions, weather conditions, and fire behaviour parameters all within planned limits?
- Was burning technique and ignition pattern correct?
- Was fire confined to intended area?
- In the case of plantations, the amount of over-storey scorch as well as the amount of litter remaining?
- Was burning cover complete?
- Effect on vegetation, soil, air, water and wildlife?
- How can similar burns be improved? (De Ronde et al., 1990)

12.7.5.2 Post-Burn Management in Savannas and Grasslands

The key to success of most prescribed fires on rangeland lies with the effectiveness of post-burn management (Bailey, 1988). In some savanna systems the plants are in a weakened condition after the fire and are susceptible to further injury by grazing animals, whereas in others the plants

are more tolerant of heavy grazing pressure. In conservation areas such variations in response are important in conserving biotic diversity. In order to understand the response of the system to management, it is important that consistent policies are applied and that an efficient and effective monitoring system is in place. This should include post-burn observations by managers. It should be remembered that burning is but one tool in an overall management plan. If no such post-burn management plan exists, then one should not be surprised if the long-term objectives for burning are not realised.

It is recommended that, when burning to remove moribund and/or unacceptable grass material, grazing be applied as soon as possible after the burn to take advantage of the highly nutritious re-growth of the grass plants. There is a lack of clarity as to whether rotational or continuous grazing should be applied after the fire. However, there is complete consensus amongst rangeland scientists on the necessity of applying a rotational resting system when prescribed burning is used (Zacharias, 1994; Kirkman, 2001). This involves withdrawing a portion of the rangeland from grazing for an extended period of at least a growing season or longer (6–12 months) to maintain the vigour of the grass sward and enable seed production to occur for plant recruitment. The rest period is applied during the season prior to the prescribed burn. In terms of rotational grazing after a burn great success has been obtained with the “open camp system” developed by A. Venter and R. Drewes in KwaZulu-Natal in South Africa. This involves burning a camp and grazing it as soon as possible after the fire after which the

livestock are moved rotationally to other camps until such time as the burnt camp is ready to be grazed again. By following this procedure, the burned rangeland is maintained in a palatable and nutritious condition for as long as possible after the burn to the benefit of the livestock. The same procedure is then followed in subsequent years. This system presupposes the availability of adequate camps to apply this form of grazing management. In situations where there are few grazing camps available, emphasis must be given to applying a rotational resting system. Where there are no camps, as occurs in communal grazing areas like the Transkei in South Africa or the Ngorongoro conservation area in Tanzania, large enough areas need to be burnt to avoid over-utilisation of the burned area. This practice will also *de facto* result in a resting treatment being applied to the unburned area, which is initially less attractive to grazing animals.

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13

WILDFIRE SUPPRESSION

Michael F. Calvin

13.1 INTRODUCTION

In principle, suppression of wildfires is a simple task. Eliminate the fuel or remove the heat, and the fire stops. However, both the complexity and variability of the fire environment makes the task of firefighting one of the most challenging jobs there is. The goal of fire suppression is to minimise or prevent damage caused by a wildfire in the most cost-effective means possible, while providing for safety first.

To be successful, fire suppression requires strong leadership skills. People put out fires. Therefore, firefighting is primarily a job of both organising and supervising people.

13.2 WILDFIRE SIZE-UP

Size-up is an estimate of the needed actions and resources required to extinguish a fire. It is made during the following stages of the fire:

- Prior to receiving a report of fire.
- When you receive the fire report.
- While you are travelling to the fire.
- When you first see the fire or smoke.
- Upon arrival at the fire scene.
- During the initial attack and the entire life of the fire.

Gathering information at each of these stages is a critical part of the fire suppression task. The first thing to do at the scene of the fire is to size up the entire situation to determine how best to attack the blaze. This may require walking or scouting entirely around the edge of a fire. If you are fortunate, you will be able to see the entire fire on arrival. Sizing-up the fire is of great importance, for it will provide you with essential information about the fire and the territory in which it is burning. Without such knowledge in the beginning, your attack may be completely ineffective.

Throughout the size-up process and for the fire's duration, three questions must be asked:

- What has happened?
- What is happening?
- What will happen?

13.2.1 Prior to Receiving a Report of Fire

- *Weather conditions.* What are the current weather conditions and how will they affect fires? What is the expected weather forecast?
- *Recent fire occurrence and behaviour.* How have recent fires behaved? These fires can provide valuable insight of the expected behaviour of new fires.
- *Fuel conditions.* What are the conditions of the fuels? Is the grass green or is it cured (dried out)? Have the larger fuels dried out due to lack of rainfall?
- *Time.* What time of day is it? Fires starting midday could be harder to control than those starting early morning or early evening.

13.2.2 When You Receive a Report of a Fire

- *Location.* Understand the exact location. Use maps and write down location of fire.
 - *Person reporting fire.* Write down the person's name in case additional information is required.
 - *Best access.* What is the fastest way to the fire? Confirm on map.
 - *Fire behaviour.* What is the size of the fire, its rate of spread (slow/fast), direction and cause.
- E. *Threats.* What is the danger to life, property or other resources.

13.2.3 En Route to the Fire

- *Knowledge of fire.* Think about fuels and terrain, access roads and fire barriers.
- *Backup forces.* What types are available and where are they located?
- *Weather indicators.* What are the actual weather conditions as you approach the fire, especially the wind?

13.2.4 When You First See the Fire or Smoke

- *Fire behaviour.* Check fire size and the smoke column's height, colour, direction and shape.
- *Verification.* Verify your expected behaviour of fire, relative to the forecast and the resulting smoke column.

13.2.5 Upon Arrival at the Fire Scene

IMPORTANT! Take a minute and calmly look at the total fire picture. The next few minutes are critical to the success of your initial attack. The first thing to do at the scene of the fire is to size-up the entire situation and determine the best method of attack. If you "go off in all directions", little will be accomplished. Factors to consider are:

- Size of the fire.
- Location of fire head – be sure you know what's in path of fire.
- Point of origin and cause – preserve evidence.
- Time of day.
- Property and other values threatened.
- Weather at fire – wind speed and direction, variable or steady?
- Behaviour of fire – how fast is the fire spreading? How high are the flames? Is it spotting? How far? Is it hotter than usual?

- Fuel type and arrangement of fuel – how clean is the fire burning? Any aerial fuels burning? Fuels in path of the fire: Do they change and if so, how will they affect the fire?
- Terrain or topography – slope and aspect, natural barriers, access roads.
- Safety factors – placement of personnel and equipment, escape routes and safety zones.

As soon as you have scouted the fire, you should plan an immediate attack, taking into consideration the fire situation and the availability of personnel. Your knowledge of fire behaviour and suppression methods will be most helpful in determining how you are going to fight the fire. Factors to consider:

- SAFETY – public and firefighter safety is your first concern.
- Threats to life and property.
- Location of attack – head, flank or rear. Initial attack should be aimed at stopping the head if at all possible.
- Method of attack – direct or indirect. Don't try the impossible.
- Location of control lines – take advantage of barriers.
- Estimated completion time of line construction. Make allowances for physical limitation of crew.
- Estimated probable spread and behaviour of fire.
- Possible danger spots – fuel build-up, bogs, etc.
- Crew deployment. Use crew as a team and don't scatter.

Experienced firefighters go through these steps without thinking about them. To gain this experience, you will need to consciously go through each step until they have become a part of your initial attack thinking process.

13.2.6 During the Initial Attack and the Entire Life of the Fire

Remember the fire is constantly changing. Continue your size-up throughout the life of the fire. Many fires have been lost and people killed or injured due to sudden weather changes impacting fire behaviour.

To summarise: In size-up, decide where the fire is most likely to spread. Look for spot fires and decide if they need attention before you start action on the main body of the fire. Consider buildings, power and telephone lines, bridges, crops, and other property located in the probable path of the fire. Exert every effort to save somebody's home, but do not jeopardise the control action on the fire to save something that can be replaced or is of little relative value compared to the potential damage the fire could cause if allowed to go unchecked. Consider also the safety of yourself and the personnel with whom you are working. Your planning should incorporate the method(s) best suited to a particular situation, making allowances for changes that are likely to occur.

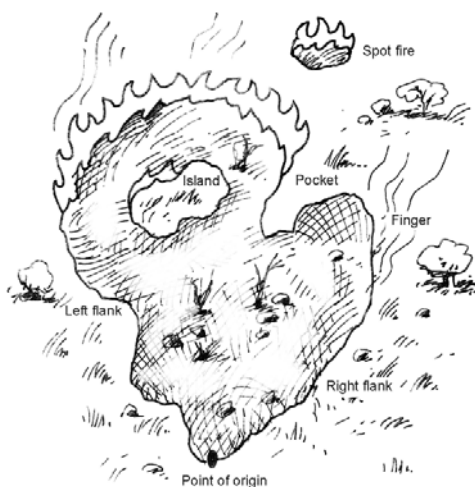
13.3 SUPPRESSION TACTICS

13.3.1 Parts of Fires

In order to communicate information and instructions on a fire, there is a need to use standard terminology. Some of the most important terms

are those describing the parts of a fire (Figure 13.1):

- *Head* – the front section of the fire spread. It is usually moving with the wind and frequently does the most damage. Usually, the head of the fire should be stopped first.
- *Origin* – the spot where the fire originates or starts. This can usually be determined by evidence such as a pile of smouldering debris or by signs of the fire on trees and brush.
- *Rear* – that area of the fire backing against the wind.
- *Flanks* – each fire has two (left and right).
- *Fingers* – generally found on the head and flanks. These are long narrow strips of fire extending out from the main fire. They will usually occur when the fire hits an area, which has patches of both light and heavy fuels. The light fuel burns faster than the heavy fuel, giving the fingered effect.
- *Pockets* – indentations in a fire edge formed by fingers or slow burning areas. When a fire edge contains deep indentations of unburned fuel, these are termed pockets. A fireline should ordinarily be built across the mouth of the pocket, and the pocket then burned out. If the line is built directly on the fire edge, more line is required, and the unburned area in the pocket is subject to fire pressure on both sides. Fire suppression activity inside a pocket area is ill-advised, as it is a dangerous place to put personnel and equipment
- *Spot fire* – the spotting effect of a running fire. Spot fires may easily occur one or more kilometres in advance of the main fire, though



they more commonly occur within 200–500 m of the main fire. These spot fires must be suppressed or they will become head fires. A spotting fire presents a hazard to fire suppression personnel and equipment since they could become trapped between two lines of active fire.

- *Island* – an area within the burn area which did not burn (e.g. marshes, areas of sparse fuels).
- *Perimeter* – the outside boundary of a fire area. The perimeter of a fire is the total length of the outside edge of the burning or burned area. It is constantly changing until control is established.

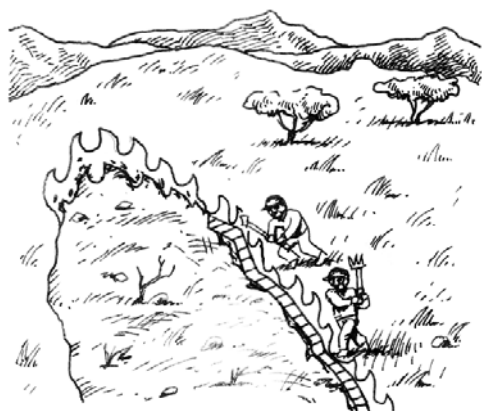
13.3.2 Types of Fires

There are three general types of fires:

- *Surface fire* – burns away the low-level fuels and ground litter.

Figure 13.1. Parts of a fire (M.F. Calvin).

13.2



- *Crown fire* – burns through the treetops. This type of fire is very dangerous and fast moving, and is usually backed-up by a following surface fire.
- *Ground fire* – burns partially decomposed organic materials such as muck and peat below ground level. This type of fire is difficult to suppress and is hazardous to firefighters. It will burn less than one centimetre to many meters in depth. When it is necessary to cross the burned area, caution must be used. Cross only if absolutely necessary and use a long pole to probe ahead for deep burning pockets. Usually this type of fire is started by a surface fire, which was suppressed before the ground fire could be suppressed.

13.3.3 Suppression Methods

The overall strategy for suppressing a wildfire is control of its perimeter. This means that firefighters must establish a clear fireline that encircles the

fire. This strategy is the same whether using water, a hand-prepared line or a tractor plough line. Controlling the fire's perimeter requires you to anticipate the fire's behaviour and make skilful use of natural and man-made barriers.

Fire personnel have a choice of two primary methods for combating wildland fires – direct attack and indirect attack. The method selected is determined by fuel types, fire behaviour, available personnel and equipment, and firefighter safety.

13.3.3.1 Direct Attack

Direct attack consists of a series of actions to cool, drown, smother, beat out, starve, or otherwise extinguish the flames of a burning fire. As the term implies, the control line is constructed along and directly on the edge of the fire. Direct attack is used on small fires, fires that are burning in light fuels, ground fires, on the flanks or rear of larger fires, or where the burning intensity, heat, smoke, and terrain will allow (Figure 13.2).

Fireline construction standards will vary based on the slope, fuels, topography, weather conditions, the part of the fire being attacked, the size and intensity of fire, and the equipment and personnel available. Firelines are placed directly on the edge of the fire. In light fuels such as grass, the fireline may consist of a black line where the fire has been put out by beaters or water. In heavier fuels, the fireline may have to be constructed down to mineral soil. All unburned material is removed to the outside of the fire perimeter.

Figure 13.2. Direct attack (M.F. Calvin).

The advantages of direct attack are:

- Limited chance for fire to gain momentum or size.
- Reduced damage to resources.
- Uncertain elements in burning out are eliminated.
- Reduced danger of fire crowning.
- Safety. If necessary, you can escape into burned area.
- Advantage is taken of burned out areas along the control line.

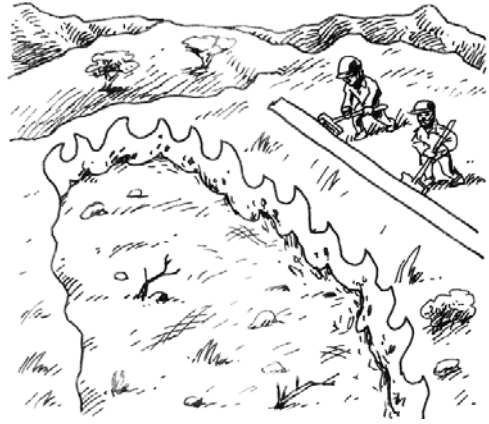
The disadvantages of direct attack are:

- Working in heat and smoke.
- More mop-up and closer patrol is required.
- More danger of breakthroughs and spot fires.
- Control line generally follows fire edge; is longer and irregular.
- May not take advantage of existing natural or manmade fire barriers.

If you employ direct attack, take advantage of wind lulls by knocking down hot spots. If possible, time attack to coincide with the fire entering lighter fuels. If water is available, use it to cool the flames so that firefighters can get in close to the fire. In addition, scatter any heavy fuels next to the fireline to avoid fire jumping the line.

Safety comes first. Don't attack the head of a fast-moving fire.

If what you are doing does not feel right, then don't do it! Back off and come up with a different plan.



13.3.3.2 Indirect attack

Indirect attack is a control action conducted from a variable distance – usually parallel to – the edge of a fire in such a manner as to deprive the advancing fire of fuel and thereby halt its further progress.

Indirect attack is used when the burning intensity, rate of spread and working conditions (heat, smoke, terrain) are too extreme or if there are too few available personnel. It is also used to take advantage of good natural or manmade fuel breaks and to straighten fire lines (Figure 13.3).

For example, when a fire is too large and spreading too fast, build the fireline safely away from the fire in a flanking attack, starting from anchor points and working around the head of the fire, avoiding sharp angles. Burn out the unburned fuels between the control line and the fire, and keep your eye on the head of the fire.

Figure 13.3. Indirect attack (M.F. Calvin).

The advantages of indirect attack are:

- You are not working in the heat and smoke.
- Takes advantage of changes in fuel types.
- Eliminates irregularity of lines.
- Permits taking advantage of the natural and man-made features.
- Permits precision teamwork.

The disadvantages of indirect attack are:

- Sacrifices acreage.
- Can be dangerous. You may be flanked or over-run by the fire.
- Fire may change direction suddenly.
- Backfire or burnout operations may go out of control.

If you employ an indirect attack method, establish lines in lighter fuels, make them as straight as possible and make use of natural barriers. Use caution when conducting backfire or burnout operations and take advantage of the weather. Don't over-extend yourself or take unnecessary chances with personnel and equipment. Keep track of all counter-fires.

13.4 SUPPRESSION TECHNIQUES

Once a fire suppression tactic is selected, the next step is to apply the available resources in order to control the fire. These techniques consist of two principle activities – cooling or extinguishing the fire to check its advance and controlling its perimeter by eliminating burnable material.

13.4.1 Fire Attack with Hand Tools

Hand tools such as beaters, spades, chainsaws and rakes are the primary tools used for fire suppression. Hand tools are used to cool and extinguish the fire and to build fireline. Key to the effective use of hand tools is the organisation of hand crews. Crews are usually organised in groups of 5 to 20 people with a crew leader. Smaller crews are good for initial attack, since they can be easily transported to the fire scene in a small truck. Crews may range from the highly organised, who train and work together on a regular basis, to groups of local people who have little or no experience. It is far more effective and safer if the personnel are organised into crews under the supervision of an experienced firefighter.

The tools used will depend on availability and fuel type. In grass, beaters and hoes are the primary tools used. However, as the fuel becomes heavier and shrubs and trees become more prevalent, a broader variety of tools, including more cutting tools, are required. As fuels change, crew crews also need to change tactics. There are three basic methods of hand crew organisation:

13.4.1.1 Alternative Advance

(Squad Method, Passing, Leap-Frogging)

Each crew is assigned particular portions of the line. As the tasks require distinct tools, the crew is divided into two groups with the cutting tools in front. In each group, the personnel are placed far enough apart to work safely and complete a short segment of fireline. When the fastest person arrives at a completed portion of line, he or she passes the rest of the firefighters and begins working on a new portion of the fireline as assigned.

The primary advantage of this method is that it doesn't require close supervision (each person knows what their job is) and permits the use of untrained personnel.

13.4.1.2 Progressive Method

Different from the above method, each firefighter advances without changing his or her location in relation to other firefighters. Each firefighter uses a technique that corresponds to the tool assigned. The work is done utilising the best aspects of each tool and then advancing. The last person in the progression is responsible for ensuring the fireline is complete. Typically a crew is organised in the following sequence: Line locator, cutting tools, raking tools, burnout, and holding. This method works well in medium fuels such as fynbos.

13.4.1.3 Individual Assignments

Personnel are distributed at intervals around the perimeter of the fire, with each assigned a portion of line to construct. This permits immediate and simultaneous work around the perimeter. However, safety of personnel must be a primary consideration prior to implementing this method. If there is a rapid shift or change in fire behaviour, personnel can be separated and very much at risk. Factors to consider when using hand crews are:

- Safety is the number one priority in all situations.
- Work a safe distance apart (four metres when using cutting tools).
- In hazardous situations, always post a lookout who can alert the crew in case of any changes in fire behaviour.
- Ensure proper supervision. Inexperienced crews require greater supervision (minimum one supervisor to 5–10 people, depending on the situation).
- Place crews based on their capabilities and experience.
- Keep track of where crews are, using portable communications if available.
- Provide crews with adequate food, water and rest.
- In areas where the threat of wild animals exists, provide for crew protection.

13.4.2 Fire Attack with Water

Water is extremely effective against fire. If used correctly, water can cool a tremendous amount of flame. Water can be delivered in a variety of ways (see Equipment section). Pumpers, where access is available, can spray water while moving or remain stationary and lay hose to extend the nozzle to the fire. Backpack pumps can also be very effective in lighter fuels and where access by a pumper is not feasible.

During initial attack, water is mainly used is to knock down the flames and allow personnel with hand tools to move in closer and prepare a fireline. Some factors to consider when using water are:

- Always aim the water stream at the base of the flame and on the fuel that is burning.
- Work in tandem with hand crews if possible. Follow-up with a backpack pump behind a beater can be very effective.
- Keep track of the amount of water left in the pumper.

- Safety considerations determine all pumper tactics. Do not place yourself or equipment in a position that would be unsafe if the water ran out or the pump had a fault.
- Always start working from an anchor point. Don't drive through unburned fuel in the path of fire's spread.
- Work parallel to the fireline (less water wasted).
- Take into consideration where and how additional water will be obtained.

13.4.3 Aerial Attack and Support

Except in limited parts of Africa, aerial support is rarely available. However, where available, aircraft can perform a variety of firefighting missions including reconnaissance, water and chemical dropping, and transportation of firefighters and equipment (see Equipment section). They can be a very effective, but expensive, firefighting tool. The incident commander must evaluate whether conditions warrant aircraft use and determine if they can be used in a cost-effective manner.

The following are tactical considerations for various aviation missions:

13.4.3.1 Dropping of Water (or Chemical Solution) by Fixed-Winged Aircraft and Helicopters

- The purpose of water drops is to knock the fire down and allow ground forces to work closer to the fire. Drops should not be used to try to put the fire out.
- Dropping water without ground follow-up is highly ineffective and wastes money.
- Water drops can be hazardous by knocking loose material from trees. Ensure ground crews stay clear of the drop zone until it is safe to return.
- Use reconnaissance ("spotter") or bird-dog aircraft to help direct the drops.
- Air drops are more effective on small fires than on large fires.

13.4.3.2 Helicopter Transport of Personnel and Equipment

- The pilot should feel comfortable with the assignment.
- Ensure there are landing zones that can accommodate the type of helicopter being used.
- Ensure landing zones do not compromise firefighter safety.
- Ensure crews are well supervised when working around helicopters.

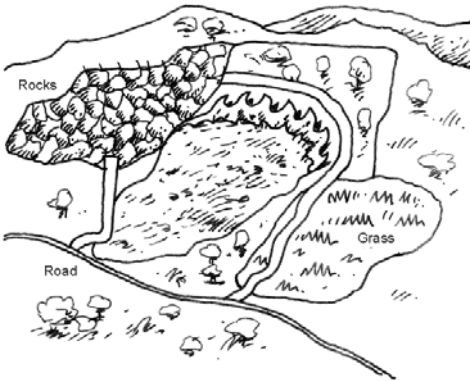
Note: This type of mission requires a support team of personnel trained in helicopter operations.

13.4.3.3 Reconnaissance and Aerial Supervision

Light aircraft can perform a useful role in providing information about the fire situation to ground forces. Often, the aircraft may serve as a platform for supervising fire operations:

- Ensure the aircraft has radio communication with ground crews and with headquarters.
- Staff the aircraft with a person experienced in fire behaviour and fire tactics.

13.4



13.4.4 Fire Attack with Mechanised Equipment

Tractors, ploughs and road graders can be used effectively to build a fireline if the terrain and fuel type permit. Generally they may only be used where the ground is level and the fuel is grass or light brush. As with other methods, be sure to start from a good anchor point.

13.5 FIRELINE LOCATION

Placement of firelines is key to controlling the fire. Bad placement can increase the time it takes to construct the line, thus causing the fire to grow larger. A fireline that is not appropriate for the fuel or weather conditions can lead to the fire jumping over the line.

The following are principles that should be followed when deciding where to place a fireline:

- Locate the fireline as close as possible to the fire's edge.
- Make the fireline as short as possible.
- Take advantage of natural (rivers, stream beds,

rock, etc.) and man-made (roads, firebreaks, etc.) barriers (Figure 13.4).

- Avoid sharp angles.
- Always anchor firelines to existing barriers or to extinguished portions on the border of the fire.
- When possible, put the fireline through open areas to reduce work.
- Use a line locator if necessary to flag or mark the firelines path.

13.6 DIRECTION OF FIRELINE CONSTRUCTION

It is usually safer to build the fireline uphill. This minimises the danger of the fire crossing the slope below the crew and sweeping up to trap them. Building a fireline downhill can be particularly hazardous on steep slopes and fast-burning fuels. The decision to build a fireline downhill should only be made by a competent firefighter after complete scouting of the proposed route. If the decision is made to build line down a steep slope with fast-burning fuels, the following applies:

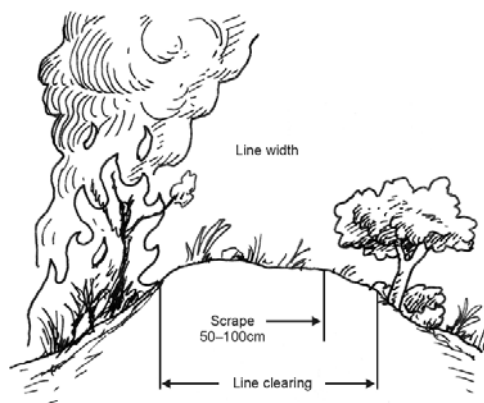
- Anchor the flank of the fire at the bottom of the slope.
- Establish communications with a person who can see both the fire and work area.
- Make certain that the crew can rapidly reach a safety area in case of flare-up.
- Use direct attack whenever possible.

13.7 LINE CONSTRUCTION

The purpose of building line is to remove burnable material in order to form a barrier that the fire

Figure 13.4. Utilise existing barriers (M.F. Calvin).

13.5



cannot pass. Line construction varies with fuel type, weather conditions and personnel available.

Firelines must be of adequate width. As a rule of thumb, if attacking the head of a fast-moving fire, the width must be at least twice the height of the combustible vegetation. On the flanks, the fireline must be at least equal to the height of the combustible vegetation (Figure 13.5). For creeping fires in light fuel, the fireline should one metre and the flank one-third of a metre. In order to prevent fires from creeping across firelines, a path of 50 cm to 1 m should be cleared to mineral soil. In lighter fuels such as grass, black lines may be used if they are securely out.

The following general rules apply for three major fuel types:

13.7.1 Grass or Open Grass Woodlands

If the grass is below 0.5 m in height, a black line can often be used without the need to scrape fireline down to mineral soil. The key is to ensure that the fire's edge is completely out. This can be

accomplished with water or beaters. Always keep an eye on the previously built line to ensure the fire does not flare up. Take full advantage of roads, footpaths and other existing barriers to place the line. Shrubs and trees that are not a threat, such as *Acacia* and other fire-resistant species, should be left. Special attention should be given after wet years when the grass fuel load can be very high and can contribute to extreme fire behaviour. In this case, a black line alone may not be sufficient to hold the fire.

13.7.2 Fynbos and other Flammable Shrub Types

Fireline construction in these types of fuels presents special challenges. Where a high portion of dead fuels exist and live fuel moisture is low, fire behaviour can often be extreme. The typical rugged and steep terrain often associated with this fuel type complicates access and contributes to dangerous fire behaviour. Particular attention must be paid to crew safety. Under these conditions, the fire's head cannot be attacked directly. The best tactic is to begin building line at the point of origin working along the flanks toward the head of the fire.

On larger fires, indirect attack must be used to take advantage of ridge-tops, roads, stream-beds, rock formations or any other point where the fire behaviour is less severe and personnel can safety work.

The progressive method of line construction works well in this fuel type. Hand tools should include a high proportion of cutting tools for each crew. Ideally, the lead tool should be a chain saw with one or two people to scatter the cut brush. If not available, then use two to three cutting tools

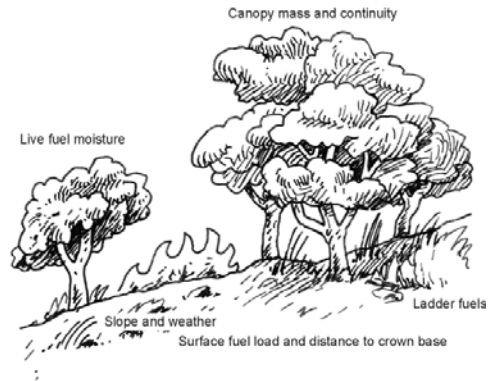
Figure 13.5. Line width (M.F. Calvin).

working a safe distance apart. This lead group cuts a coarse path through the brush. Following close behind are a combination of cutting and scraping tools to improve the line and bring it down to mineral soil. The last person is responsible for ensuring that the line is completed to standards.

13.7.3 Closed Canopy Forests of Flammable Trees
Exotic plantations of *Pinus* and *Eucalyptus* present another difficulty to the firefighter, due to their inherent flammability and potential for a crown fire. This potential exists where there is sufficient mass and continuity of aerial fuels and the bases of the crown are exposed to intense heat from fuels burning below them. Crown fires create conditions where spotting and extreme behaviour can cause the fire to jump control lines and create hazardous conditions for crews. Fireline construction is problematic since it is usually not practical or advisable to construct a fireline that is wide enough to stop a crown fire.

Assessment of crown fire potential is therefore crucial to both proper fireline placement and construction. Factors to consider are:

- Are the crowns of the trees touching and close enough to sustain crown fires?
- Is there sufficient mass or quantity of fuel in the canopies to sustain crown fires?
- What is the slope? Slope increases the potential for crown fire.
- What is the distance between surface fuels and the base of the crowns? The smaller the distance, the greater the potential.



- What is the surface fuel load? Higher loads increase fire transfer to the crowns via convection and radiation.
- What is the live fuel moisture of standing trees? Trees with low moisture content in their live components are at greater risk of crown fires. Unless measurements exist, judgement must be based on time of year and the amount of precipitation received.

Generally, the tactics for this fuel type focus on controlling the surface fire and reducing the threat of crown fires near the control line. Where the risk of crown fire is minimal, surface fuels determine the line width and placement. However, care should be taken with individual trees that could pose a threat to the line. Where there is a sufficient risk of crown fire, care must be taken to reduce the possibility of crown fires near the control line. This can be accomplished in a number of ways:

Figure 13.6. Crown fire factors (M.F. Calvin).

- Reduce the crown mass and continuity by thinning the number of trees in the vicinity of the fireline.
- Remove ladder fuels that can carry fire into the trees by pruning branches.
- Lessen surface fuel loads by cutting and scattering.
- Knock down trees that have the potential to extend into the crowns.

Safety should always be a primary concern when the risk of crown fires exists. Tree canopies create the potential for entrapment of firefighting crews by obscuring their view of the fire. Use lookouts, if necessary, to keep the crew advised of the fire situation. Plan escape routes and make them known.

13.8 BURNOUT

Burning out is done to increase the area of fuels burned without the additional work of the crew or machinery. If there are unburned areas between the fire and the line, then the line is not secure until the burning out is done. Burnout starts from the fireside of the control line and utilises elements and techniques of firing similar to those used in prescribed burnings (see section on Prescribed Burning). It is considered good practice for the burning to occur as the control line is being constructed. If the line ascends a slope, the burning should be done in sections working from the top to the bottom. During the burning out, all personnel must be alert for spot fires. Place personnel equipped with beaters, backpack pumps and spades along critical areas of the fireline.

13.9 BACKFIRE

Backfiring is distinctly different from burning out. It is an aggressive move against the fire's spread. It involves setting a fire along the inner edge of the fireline toward a going fire with the expectation that it will be pulled toward the oncoming fire and burn out the intervening vegetation. It is usually a measure of last resort. Backfiring requires expert knowledge of fire behaviour, the local weather conditions, and the local fuel types. A backfire must be executed within a narrow fire behaviour window. Conditions that are too extreme could cause the set fire to jump the control line. Conditions that are too moist will cause incomplete burning of the fuels in front of the fire causing a significant problem later if the fire intensity increases. The keys to a successful backfire are:

- Operations should be directed by an experienced leader.
- A backfire should be started as close as possible to the main fire, balancing the time needed to complete operations against the fire's rate of spread.
- Once the firing has started, it is critical that all vegetation be burned between the main fire and the backfire.
- The main fire and the backfire should meet at a safe distance from the fireline.
- Sufficient firefighting forces should be assigned to hold the fire.
- Updates on local weather conditions should be provided.
- More fire than can be controlled by assigned personnel should never be started.

13.10 MOP-UP AND DEBRIEFING

13.10.1 Mop-up

After the fire has been contained, many tasks still have to be done to make the fireline safe and put the fire out completely. The objective of mop-up is to put out all remaining embers or sparks to keep them from crossing the fireline. Mop-up consists of two phases: Putting the fire out and disposing of fuel either by burning or removal. The mop-up crew starts working as soon as possible after the line has been constructed. The most threatening situations are dealt with first, such as smouldering logs, burning roots and hot spots that could spread the fire outside the fireline. If available, water is the most effective tool in cooling and preventing the further spread of the fire.

On small fires, all fire should be extinguished in the mop-up phase whenever possible. On larger fires, mop-up should be done on enough of the area adjacent to the fireline to prevent fire from blowing, spotting or rolling over it. Patrol is the tail end of the mop-up phase, when firefighters systematically move back and forth over the control line to check for and suppress hot spots. Each patrol member is designated a specific area. Remember, *the fire is not out until the Incident Commander declares it out!*

13.10.2 Debriefing

It is good practice to hold a debriefing and critique after the fire. This can occur just between key staff or it can include crews and other personnel assigned to the fire. Take the time to review all the decisions made at various stages of

the fire. Use these sessions to improve performance on the next fire by asking two questions: What did we do right and what can we do better next time?

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14

WILDFIRE INVESTIGATION, FIRE INSURANCE, ECONOMICS AND TRAINING

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14.1 INVESTIGATING CAUSE AND ORIGIN OF WILDFIRES

14.1.1 Introduction

A wildfire can be described as “any unplanned fire burning timber, brush, grass, or cropland requiring suppression actions” (National Wildfire Co-ordinating Group, 1978). The moment such a fire escapes from one property, causing damage to another property or properties, legal action may follow. Whether a land manager is – after a wildfire – faced with the probability of being on the side of the Plaintiff or the Defendant if fire damage was experienced, it is important that certain action is taken as soon as possible after the fire, because:

- Evidence on the site of the wildfire will get lost over time.
- Potential witnesses should be identified and

approached as soon as possible.

- People have short memories. Details of times and events should be recorded while still fresh in the minds of those involved in fighting the fire, those responsible for fire protection measures and also those who have witnessed the crucial episodes of fire ignition or of fire behaviour.

It is not within the scope of this handbook to train the readers as wildfire investigation specialists, but actions after the fire has been brought under control – in particular, around the site of fire origin – can protect vital evidence, which may be required by the wildfire investigating officer at a later stage.

14.1.2 Protecting the Site of Fire Origin

Once the site of wildfire origin has been identified (even if this area is approximate and comprises a

hectare or more) this area should be clearly demarcated with a bright red-and-white coloured tape, marked or painted trees, poles, or other outstanding points in the landscape around the site of fire origin. Workers or contractors, making use of the area when, for example, exploiting timber, should also be warned to stay away from the site. Apart from marking/demarcating the perimeter of the fire origin, the following rules should also apply:

- Timber within the fire origin perimeter should not be exploited until after the on-site investigation has been completed.
- Soil or litter layers within the marked area should not be disturbed.
- The site should be out of bounds for anyone not involved in the fire investigation until the investigation has been done.
- Where a wildfire burned through a timber stand or stands, trees that were not exposed to crown fire – where bark scorch patterns are clearly visible – near crucial landmarks that could have played a role in changing fire behaviour (such as where fire jumped a road or fire belt) should also be conserved, and exploitation delayed. The bark scorch pattern may provide vital evidence for the wildfire investigating team/officer.
- Witness reports.
- Photographs, especially those taken immediately after the fire.
- Aerial photographs.
- Videos or films taken during the wildfire spread.
- Records of telephone calls made before and during the wildfire.
- Accounts in connection with aerial or ground firefighting services.
- All maps of fire spread/damage caused, and internal fire reports.

The latter should also be kept in a safe place and not be shared with anyone, except with the consent of the legal representative or the company/organisation the fire manager is working for.

14.1.4 Fire Reports and Fire Spread/Damage Maps

The golden rule here should be rather to provide too much information than too little. Many companies have their own fire report format and, if possible, these reports should be supplemented with photographs and maps of the area that was burned. Pictures of damage caused are useful, while the following general guidelines may also assist:

- Make sure to include all names and full addresses of persons and organisations directly involved in the wildfire (e.g. people who assisted in firefighting) as well as persons indirectly involved (e.g. owners/managers of adjoining land affected by the fire).

14.1.3 Collection and Safeguarding of Evidence

After the fire, the fire manager should attempt to collect and keep any evidence items which might be of assistance to the investigators. These can include the following:

- The sequence of events during the wildfire, with estimated times, must be included in all fire reports.
- Status of own fire protection systems in place at the time of the fire must be provided in detail, including those not directly involved and not burned (for illustration purposes, which information may be required by the investigation team).
- A description (in as much detail as possible) of all firefighting equipment available at the time of the fire. Specific mention should be made of types and specifications of pumps used, length of fire hoses, type of nozzles, etc.
- Detail of all manpower used to combat the fire.
- Log of aerial firefighting used during the fire.
- Detail of any back-burning that was applied, with starting and ending points, times, who applied the burning, results and an indication of the back-burning line (or lines) on a map.

If specific damage was experienced, full detail thereof should be provided in the form of an appendix to the fire report, without quantifying this. A quantum of the fire damage will probably be calculated by a qualified person at a later stage.

14.1.5 Assisting in the Fire Cause Investigation

The manager of the land can assist the investigating officer by ruling out certain possible causes of the fire, or can maybe explain why a certain fire cause is a higher probability than other probable causes. For instance, if the site of fire origin is close to a road, the investigator might want to

know if the road is sometimes used by local people, and if this could have given rise to a higher arson or negligence probability. Certain areas are prone to lightning strikes and subsequent fires, while other sites might just be too remote for any human being to start a fire within its boundaries. The fire cause in such instances can then, for example, be considered to have originated from a spotting ember deposited from a fire that happened to burn elsewhere. The fire manager, knowing the site of fire origin best, can sometimes provide important clues that can assist the investigator in determining the most probable cause of a fire, in the absence of direct evidence.

The manager of the land may recall important events that can also point to possible fire causes. If, for example, the day of the fire was on a payday only hours after wages were handed out, and the site of fire origin was close to the route of a local bottle store, it is clear that alcohol could be an indirect cause for the fire. Likewise, if there were employees who were retrenched for one reason or another, and this is known to have caused unhappiness, arson can be linked to a fire, which started along a public road used by these ex-employees.

Other examples where knowledge of the area can assist in the investigation: A fire site close to a railway line could have been caused by a train or locomotive; a fire near a picnic site could have been caused by a cooking, barbeque or camp fire; a fire that started in grassland close to a public road could have been caused by a motorist discarding a cigarette butt, and a broken (downed) electrical line underneath a power line can easily give rise to a fire that started in slash underneath

that line. Common sense, and trying to figure out the obvious, can sometimes lead directly to determining the cause of a wildfire.

14.2 FIRE INSURANCE

14.2.1 Introduction

In dealing with plantation insurance, a basic understanding of “risk” is required.

14.2.1.1 Fundamental Risk

Fundamental risks are those that would normally affect countries or large sections of societies. In this class falls the famine in North Africa, the recent floods in Mozambique and widespread diseases, such as HIV/AIDS. Fundamental risk normally has widespread disaster potential and is in general terms regarded as “uninsurable” in the commercial insurance market.

14.2.1.2 Particular Risk

This kind of risk is generally restricted in its consequences. Two sub-divisions are generally recognised:

Speculative risk

Here the company or individual has a chance of gain or loss through the normal running of the business. Speculative risk is as fundamental risk not commercially insurable.

Pure risk

This is pure risk as the term indicates, and offers no chance of gain or profit. Only a loss can be the end result. It is this form of risk that is generally insured against.

14.2.2 Historical Background

For many years now plantations have been insured through the local insurance industry in South Africa. Insuring of plantations has been limited to man-made plantations. Natural forests fall outside the scope of the norm simply because it is difficult to establish the commercial value of these forests.

Lloyds of London has always played an important role with the insurance of plantations, be it either by way of a line slip directly into London or through a binder facility.

Locally growing timber was in the past insured mainly through the Insurance Timber Pool. This Pool comprised a group of insurers, which pooled their resources to offer this facility, and by doing this, shared the premiums or the losses that occurred. In those days it was the Shield that led the pool. This was dissolved years back, probably towards the end of the 1970s.

Very few of the current local insurers offer a facility for insuring timber, as this is a “pure” risk which was thought to be “accommodation” business only, probably because it was not always fully understood, and therefore the presence of unrealistic warranties on the policy made it unattractive. There were a few, however, who ventured into this “unknown” territory. These were more the cooperative type schemes that were started by the farmers. Some were successful, whilst others failed. The downside with this type of scheme was that if it was a good year with few losses, the scheme made a profit. Should it have been a bad fire season, the losses would have exceeded the claims with the net result being a partial payment to the members in relation to

the loss versus the available funds ratio. Most of the schemes have been discontinued or absorbed into larger groups.

Today there are only a handful of insurers that are prepared to underwrite timber. One of these is SAFIRE who started out at as being a co-operative scheme designed specifically to meet the needs of its members, largely from the marketing of their timber point of view. Over the years they have now emerged into a fully-fledged insurance company. Although writing the business for their own account (primary layer), they still have a re-insurance facility through Lloyds of London.

Sentrasure is another cooperative insurer engaged largely with crop-type insurance, but they extended their field of operations to include growing timber. This was absorbed by the Commercial Union and has in turn now been taken over by the Mutual and Federal.

Lloyds historically offered a "binder facility" to some of the larger brokers whereby they could, on behalf of Lloyds, underwrite plantation risks. From the two such facilities that existed, one with Price Forbes and the other with MIB (as they were known then) a combined facility has emerged. These two binders were combined (as the same Lloyds syndicate underwrote them both) and are now managed by the Admiral Underwriting Group.

Other facilities through London are also in existence but these are not solely Timber Binders as they make provision for crops, tobacco, etc.

14.2.3 Basis of Insurance

14.2.3.1 Cover

The basic cover that was investigated by plantation owners was to address the loss of their plantations from the peril of fire. As a result of this, the underlying plantation policy was derived.

Policy wordings may vary from insurer to insurer, but the policy is normally written on a "declared value basis". Policies will usually provide indemnity for damage or loss to the trees resulting from:

- Fire and/or lightning.
- Fire consequent upon explosion wherever the explosion occurs.
- Explosion consequent upon a fire on the property insured.
- Explosion of domestic boilers/and or gas used for domestic purposes or for heating and/or lighting.

Additional selected "add on" cover is also usually available. This could include the following options:

- Debris removal – the cost of clearing and removing debris following a fire.
- Water bombing – aerial firefighting costs.
- Ground firefighting – to cover charges levied by local authorities/other growers.
- Felling costs – the reimbursement of costs incurred in felling, stripping and cross cutting the timber prior to a fire.
- Cutting rights – intended to cover standing and/or felled trees where cutting rights have been acquired by the insured.

- Wattle bark – the policy is extended to include the value of bark if stated on the schedule, stripped from the trees and awaiting removal from the plantation.

The above options are only available where a basic timber policy has been purchased.

14.2.3.2 Excess

All policies carry an excess and these will vary in accordance to the cover selected. For instance, the basic policy will probably carry an excess of 15% of the loss, whereas the water bombing extension carries 25% excess.

14.2.3.3 Rates

Rates vary and operate something along the lines of motor insurance where a “no claim” rating benefit applies. That is to say, if a plantation owner does not suffer a loss during the course of a fire season, there is a downward rate adjustment for the next renewal. Obviously, there is a limit to the level to which rates can fall (maximum after seven years claim-free). There is also a differential rating scale for the different species. Pine attracts the higher rate, whereas gum and wattle enjoy a similar rate.

14.2.3.4 Warranties

Policy conditions do vary, but all policies are subject to the compliance of certain warranties. These may well vary, but generally relate to the provision of firebreaks, firefighting equipment, watch towers, management control, the restriction of the type of activities undertaken within the plantation and the need to provide proof of the extent

of the loss (value). These warranties are binding on the contract of insurance. In other words, they need to be adhered to, to the letter. Failure to do so could result in the claim being repudiated.

14.2.4 Basis of Valuation

The more mature the timber is, the more valuable it is. In view of this basic fact, a policy will have a timber schedule in which all the compartments are listed and the planted areas and their age class reflected.

The insurance premium is determined by this schedule and the values reflected therein. Claims too are adjusted on the basis of the declared values shown in the schedule.

Premiums are based on the rate applicable to that specie, multiplied by the sum insured (value) taken from the schedule. It is therefore very important to establish as accurately as possible the correct value of the standing timber. Failure to do so could result in an excessive premium being levied (if the values are too high) or, conversely, a claim being absorbed in the salvage realised following a loss, where the net return from the salvage exceeds the declared sum insured.

There are a number of ways of doing this, but the two most commonly used are the Faustmann formula and/or the SATGA tables. Both are acceptable as they provide a market-related value and, as the policy is written on a declared value basis, should an unrealistically low value be used to insure the timber, the benefit to the policyholder could be nullified by the salvage obtained when the loss is assessed.

It is also for this reason that natural forests or plantations are not commonly insured, as there

is no real mean against which the value can be related. In the case of man-made plantations it is fairly easy to determine the market value of the timber.

14.2.5 Claims

Following a claim, insurers will usually appoint a Loss Adjuster who, together with the insured, will quantify the extent of the loss. Claims will always be settled net of salvage and less the excess written in on the policy.

14.3 TRAINING ISSUES

14.3.1 Training Strategy

Training is important at all levels of fire management, from basic fire fighting procedures to fuel management, fire ecology, fire behaviour and fire control strategies at senior level. The type of training required can range from a short practical course in firefighting to post-graduate specialisation in fuel dynamics, integrated fire prevention, fire effect studies or fire behaviour modelling, and it is important to determine what degree of training is required, at which level, within the fire management and fire ecology sphere.

In Africa there is sometimes a critical lack of formal and informal training in fire-related fields and although this problem is more serious in some countries than in others, the reality is that most people involved in basic firefighting – as well as at all degrees of management – have not been trained adequately to satisfy required knowledge levels.

The problem can in most cases be identified within the formal training environment, presented

at institutions such as technical colleges and universities, but can also be as a result of a lack of in-service training provision within disciplines involved in fire management and fire ecology application, such as in the agricultural environment (e.g. the training of farmers and their employees) in forestry companies (e.g. training of firefighting crews, fire bosses and forest managers), in nature reserves (e.g. at ranger level and formal undergraduate and post-graduate training of fire ecologists) and in various sectors of formal government.

14.3.1.1 Training Requirements for Ground Fire Fighting Crews

In South Africa various forms of formal and informal training courses in firefighting exist, particularly with regional and other firefighting services and organisations, forestry companies and armed forces. However, in some African countries these training facilities do not exist, and training has to be arranged with the assistance of other national organisations such as the UN, EU or through other aid agencies. It is extremely important that this kind of training is provided at grass-root level, and this is applicable to both training in fighting wildfires as well as the application of prescribed burning.

14.3.1.2 Training Requirements for Fire Bosses

As the fire boss will be in control of a firefighting force, he/she has to be well trained in firefighting procedures and tactics, as well as in prescribed burning planning, application of burning techniques and post-burning operations. In South Africa some

formal and informal training can be arranged at fire boss level. In countries where such training is not available, sending of fire bosses on training course elsewhere in Africa (or even abroad) should be considered.

14.3.1.3 Training Requirements for Fire Managers

Fire managers can be trained at various levels. In South Africa fire managers can be trained at regional Services level, at technikons (e.g. through Agriculture, Nature Conservation and Forestry Departments) and at certain universities. At the University of Stellenbosch and the Port Elizabeth Technikon (Saasveld campus) post-graduate training is now also available.

For specialised further training of fire manager specialists, post-graduate training in countries such as the USA or Canada may be considered, although the "South African option" is becoming very popular.

One of the biggest problems facing most African countries (including South Africa) is that basic formal training is still not geared to train fire managers properly at undergraduate level, and that many untrained foresters, nature conservators and farm managers are still basically untrained when they enter service in the field. In South Africa steps are now taken to improve undergraduate training at technikon and university level in fire management and fire ecology. This will ensure that more fire managers will be trained in the future to fill this important need in Africa.

14.3.2 "Bridging" Courses for Fire Managers

As explained in the previous paragraph, there exists a serious problem with undergraduate training at technical and at academic level in fire management and fire ecology, and as a result many fire managers are not properly trained in many spheres of the African continent. Formal training is now available in this field (e.g. through the Saasveld campus of the Port Elizabeth Technikon Forestry Department). This institution now also arranges for certain "bridging courses" in fire management, risk and vulnerability assessment, and fire behaviour modelling, which are recommended to train fire managers without a formal fire management/fire ecology training qualification. The Forestry or Nature Conservation diploma courses at Saasveld, as well as the B-tech degree with Fire Ecology IV as a subject, are highly recommended for fire managers to be.

14.3.3 The Wildland Fire Training Centre Africa (WCTA)

Most southern African countries have regulations governing the use and control of fire, although these are seldom enforced because of difficulties in punishing those responsible. Some forestry and wildlife management agencies within the region have the basic infrastructure to detect, prevent and suppress fires, but this capability is rapidly breaking down and becoming obsolete. Traditional controls on burning in customary lands are now largely ineffective. Fire control is also greatly complicated by the fact that fires in Africa occur as hundreds of thousands of widely dispersed small events. With continuing population growth and a

lack of economic development and alternative employment opportunities to subsistence agriculture, human pressure on the land is increasing and widespread land transformation is occurring. Outside densely settled farming areas, the clearance of woodlands for timber, fuelwood and charcoal production is resulting in increased grass production, which in turn encourages intense dry season fires that suppress tree regeneration and also increase tree mortality. In short, the trend is toward more fires.

Budgetary constraints on governments have basically eliminated their capacity to regulate from the centre, so there is a trend towards decentralisation. However, the shortage of resources forcing decentralisation means there is little capacity for governments to support local resource management initiatives. The result is little or no effective management and this problem is compounded by excessive sectoralism in many governments, leading to uncoordinated policy development, conflicting policies, and a duplication of effort and resources. As a result of these failures, community-based natural resource management is now increasingly being implemented in Africa, with the recognition that local management is the appropriate scale at which to address the widespread fire problems in Africa. The major challenge is to create an enabling rather than a regulatory framework for effective fire management in Africa, but this is not currently in place. Community-based natural resource management programmes, with provisions for fire management through proper infrastructure development, must be encouraged. More effective planning could also be achieved

through the use of currently available remotely sensed satellite products. These needs must also be considered within the context of a myriad of problems facing governments and communities in Africa, including exploding populations and health (e.g. the AIDS epidemic).

While unwarranted and uncontrolled burning may greatly affect at the local scale, it may not yet be sufficiently important to warrant the concern of policy-makers, and that perception must be challenged as a first step towards more deliberate, controlled and responsible use of fire in Africa.

The prevailing lack of financial, infrastructure and equipment resources for fire management in sub-Saharan Africa goes along with a lack of human resources adequately trained in fire management. The gap between the decreasing fire management resources and the increasing fire problems in sub-Saharan Africa requires immediate response through capacity building.

As a first step, the Regional sub-Saharan Fire Management Network (AFRIFIRENET) was founded in July 2002 under the auspices of the Global Fire Monitoring Center (GFMC) and the Working Group on Wildland Fire of the UN International Strategy for Disaster Reduction (ISDR). The objectives of the network include:

- Establishment and maintenance of the network through multilaterally agreed mechanisms of communication and information sharing
- Establishment of topical sub-nets, e.g. fire monitoring, early warning of fire, wildland fire science, fire management cooperation and training, etc.

- Regular communication with network members, contribution to and circulation of International Forest Fire News (IFFN).
- Support of the establishment and facilitating access – and the use of – remote sensing and related technologies for fire and fuel monitoring, fire management planning and wildfire impact assessment.
- Creation of an early wildland fire warning system.
- Contribution to a global fuel status, fire monitoring and impact assessment programme which will secure the contribution for and by the continent.
- Improvement of integrated fire management at regional and national scale.
- Improved research and technology with regard to fire science, and streamlined technology transfer.
- Assisting in wildfire disaster management (emergency support).
- Providing/facilitating training at all levels of fire management.
- Promoting communication between the wildland fire disciplines of Africa and from other continents under the umbrella of the GFMC.
- Contributing to the New Partnership for Africa's Development (NEPAD).

In preparation of the fire management training activities, the GFMC along with the coordinator of AFRIFIRENET have prepared this *Fire Management Handbook for Sub-Sahara Africa*. Based on these preparatory activities it is intended to organise a series of international training courses "Integrated Fire Management for Fire Managers

in Sub-Sahara Africa". The training courses aim to contribute to NEPAD and will be conducted in close cooperation with the UN Food and Agriculture Organisation (FAO Forestry Department and FAO HIV/AIDS Mitigation Strategy, Forestry Sector) and the Global Observation of Forest Cover/ Global Observation of Landcover Dynamics (GOF/ GOLD) – Fire Mapping and Monitoring Regional southern Africa Team (SAFNet).

14.3.4 Objectives and Training / Capacity-Building Target

Objectives are the provision of a comprehensive advanced fire management training / capacity-building package for fire management trainers, extension officers and other fire management officers south of the Sahara, which will cover (a) an introduction to African fire ecology, (b) fuel and fire management, (c) fire prevention, (d) fire-use, (e) fire fighting, (f) fire behaviour prediction and (g) fire early warning systems and application. The target group includes African fire management specialists, trainers and extension officers responsible for fire management in nature reserves, industrial plantations, mountain catchment areas, agricultural land, and rural areas, including community-based fire management in all the biomes covering the African continent south of the Sahara.

14.3.5 Course Contents

- *Introduction to fuel dynamics*

Fuel classification by size, age and other fuel characteristics. Fuel appraisal in Africa. Fuel availability. Fuel moisture, drying rates and aeration. Fuel loading and surface-to-volume ratio (fuel density).

- *Fuel management*

Considering the “grazing” factor. Fuel reduction requirements, by biome. Fuel management in grassland (savanna and montane grassland), for bush encroachment, in rural and agricultural fuels. Fuel monitoring and management methods (including the use of the disc pasture meter). Considering wildfire history.

- *Principles of fire ecology*

African biomes: Optimum fire frequencies and burning seasons. Influencing factors: Agricultural practices (including grazing), rural conflicts, tourism, fire exclusion (lack of fire use). Fire management/ecological compromises.

- *Fire hazard/danger rating*

Fire hazard evaluation/classification. Fire danger rating models. Early warning systems. MacArthur model. African options.

- *Fire prevention*

Fire breaks, buffer zones and block burning. Fuel reduction burning. Grazing and fire use. Using the media. Public awareness and extension programmes.

- *Fire weather*

Using global monitoring systems. Weather forecasts. Fire weather statistics. Relative importance of weather parameters. Weather recording instrumentation. Prescribed burning: weather prediction. Using FDI predictions. Synoptic charts.

- *Conservation fire management*

Fire frequencies/season of burn requirements in Africa. Laissez-faire vs. block burning in savanna grassland. Fire-use options in other African ecosystems (fynbos and other shrublands, grassland and woodlands). Adjusting ecological requirements.

- *Participatory/community-based fire management*

Fire in land-use systems and causes/underlying causes for uncontrolled/unwanted fires. Community-based fire management (wildland fire prevention methods and materials, including involvement of community fire committees, schools, churches, artists, media, etc.).

- *Integrated fire management*

Regional requirements. Topography, vegetation cover and land-use considerations. Ecological requirements. Riparian zone integration. Fire hazard mapping. Regional bufferzoning. Incorporating urban and rural interface problems. Agriculture, forestry and nature conservation. Modelling grazing pattern: wildlife corridors and seasonal animal migration effects.

- *Prescribed burning*

Prescribed burning planning. Prescribed burning techniques by vegetation type (grassland, shrubland, woodland, plantation). Fire break burning. Block burning. Tracer belt preparation. Prescribed burning application. Results/damage assessment. Mopping up. Burning priorities. Smoke management.

- *Fire detection*

Aerial reconnaissance. Patrolling. Manual/unmanned towers. Tower placement.

- *Fire protection associations*

Determining regional boundaries. Fire Protection Officers. Officer's responsibilities. The ops room. African options.

- *Incident Command Systems (ICS)*

ICS structure models. ICS in Africa. Recruiting and training. International assistance (a) from Africa and (b) from abroad. Moving towards international cooperative agreements.

- *Wildland fire law enforcement*

Investigating suitable African Law enforcement models. Is the South African Veld and Forest Fire Act a model for other countries? Which adaptations are needed?

- *Fire fighting*

Training and human resources. Ground crew organisation. Equipment. Firefighting procedures (including counter firing methods). Aerial firefighting. Firefighting control. Communication. Evacuation. Traffic control. Disaster management.

- *Fire behaviour prediction*

Model selection. The Trollope models. BEHAVE. BehavePlus. Using the SURFACE, SIZE, SPOT AND SCORCH models. Use for (a) prescribed burning and (b) wildfire behaviour prediction.

- *Wildfire damage assessment and recovery mechanisms*

Considering fire intensity. Effect of fire on grassland ("dry" and "wet" season burns). Effect of fire on physical and chemical soil properties. Effect of fire on trees: Damage assessment procedures. Monitoring programmes. Erosion and ecosystem recovery. Weed problems.

- *Remote sensing*

Introduction on existing sources of remote sensing products for early warning and monitoring of wildland fires in Africa (by GOFC-GOLD Regional Fire Implementation Team, SAFNet Coordinator).

- *AFRIFIRENET, GFMC and FAO*

Participants will be given an introduction to the AFRIFIRENET within the UN ISDR, Working Group on Wildland Fire / Global Fire Monitoring Center (GFMC), and on FAO regional projects and programmes (2003–2004 timeframe).

REFERENCE

Regional Sub Sahara Africa Wildland Fire Network (AFRIFIRENET): [http://www.fire.uni-freiburg.de/Global Networks/Africa/Afrifirenet.html](http://www.fire.uni-freiburg.de/Global%20Networks/Africa/Afrifirenet.html)

FIRE HISTORY, FIRE REGIMES AND FIRE MANAGEMENT IN WEST AFRICA: AN OVERVIEW

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15.1 INTRODUCTION

Fire has long been considered a permanent characteristic of savanna ecosystems (Monnier, 1990; Goldammer, 1993). Every year large areas of the West African savanna are burned. Estimates of the extent and impact of the numerous fires¹ are uncertain and are still debated. However, it is generally agreed that fires have occurred in the environment since the evolution of terrestrial plants (Andreae, 1991), and that fire existed in the region since the emergence of savanna in the tertiary period, approximately 65 million years ago.

The different physiognomies of tropical savanna have invariably resulted from complex interactions of wildlife, humans and fire in pre-historic climates and landscapes (Schüle, 1990). Anthropogenic fire has been, and still is, among the most important factors affecting the contemporary composition, structure, and distribution

of dryland vegetation in West Africa (Swaine, 1992; Langaas, 1995).

Early concerns regarding anthropogenic fire-induced vegetation change and its impact on local climate, hydrology, land productivity and the downstream flows of major river basins such as the Niger and the Volta were expressed by colonial forest administrations established in West Africa in the late 1800s and early 1900s. The threat posed by bushfires implicated in the processes of "savannisation", the formation of "derived savanna" and the supposed desiccation of the region continued to preoccupy French and English forestry administrations throughout the colonial era (Fairhead & Leach, 1998; Wardell et al., 2003).

Shifting cultivation, bushfires and extensive pastoral land-use systems were described as the "three evils" after Professor Stebbing's sojourn in West Africa in 1934 (Stebbing, 1937).² The same value-laden tenets underscored the adoption of

the “*trois luttes*” by President Thomas Sankara and the Government of the Republic of Burkina Faso in 1985 (Government of Burkina Faso, 1985). The sustained efforts to suppress bushfires in the region have generated and perpetuated myths about the environmental impacts of fire which represent over-simplifications of cause and consequence relationships. These myths have become embedded in broader land and environmental degradation narratives, and continue to shape environment and development policies even though they are difficult to support empirically (Government of Burkina Faso, 1997a; 1997b; 1998; Government of Ghana, 1983; 1990; 1994; Ministry of Lands, Forestry and Mines, 2001).

Repeated attempts – spanning a century – to promulgate anti-bush fire legislation, to impose sanctions, to conduct educational and awareness campaigns, to adopt political slogans (“*la lutte contre les feux de brousse*”), and to establish and equip bushfire control institutions have not resulted in significant changes in customary uses of fire, fire “cultures” or the incidence of bushfires in the region. On the contrary, there is some evidence to suggest that the spatial extent of bushfires has increased in the region in the past two decades (Brookman-Amissah et al., 1980; Barbosa et al., 1999).³ In some West African countries, it is still technical capacity constraints, the lack of operational resources and the destructive practices of local resource users which are proffered as key explanations for the failure of earlier and current bushfire suppression policies (Nsiah-Gyabaah, 1996; Gboloo, 1998; FAO, 2001; World Conservation Union, 2001).

This chapter provides a contribution to the continuing regional interest in bushfires (Finnish Ministry for Foreign Affairs, 2001; Forestry Research Institute of Ghana [FORIG], 2003; CARE/University of Development Studies, 2003). A historical background is presented in Section 2 which includes an overview of pre-colonial evidence for the use of fire in West Africa before tracing the evolution of colonial responses to the bushfire “problem” and bushfire management after independence. Contemporary fire regimes in the region are presented in Section 3, with particular reference to the Sudano-Sahelian zone.⁴ Current approaches to fire management in state protected areas and public lands of West Africa are discussed in Section 4 using Senegal as a case study. Some conclusions and future perspectives are presented in Section 5.

15.2 HISTORICAL BACKGROUND

15.2.1 Pre-colonial Evidence for the Use of Fire in West Africa

annual grass fires which, sweeping over an ever-extending area of country for many decades, must now be considered in the light of a natural factor ... (Chipp, 1923).

Lightning occurs naturally during storms at the end of the dry season in West Africa but is much less frequent in the savannas of the region than in the humid equatorial areas (DeBano et al., 1998). In pre-settlement periods, lightning strikes were probably an important source of natural fires (Phillips, 1965; Komarek, 1968). Natural fires could, in theory, have occurred since the evolution of vascular land plants about 400 million years

ago. There is, however, little geological evidence of the burning of vegetation in pre-Pleistocene deposits (Stewart, 1956; Lawson, 1986). During the Pleistocene, the role and influence of fire on vegetation may have changed in accordance with climatic fluctuations (Goldammer, 1993).

The influence of fire on vegetation history in tropical areas, in general, is relatively poorly understood due to the under-representation of well-drained and arid environments in fossil records (Clark & Robinson, 1993), and due to records being “scanty or lacking” (Bartlett, 1956). Other scholars have highlighted the particular lack of literature on West African savanna compared with savanna in other parts of the world (Cole, 1986; Evans, 2001).⁵ In some cases unverified explanations for the origins of natural fires have been suggested.⁶

Research conducted during the last twenty years has started to redress the relative paucity of data regarding the historical determinants of West African savanna. Initially, fragments of wood charcoal found at several Iron Age (Late Holocene) archaeological sites in West and Central Africa provided the basis for a hypothesis that iron smelting, and the growth of trans-Saharan trade were key determinants of deforestation (Goucher, 1981). Doubts were cast on this explanation after more recent research has highlighted the important roles played by local resource users in managing and enriching agricultural and woodland landscapes (Fairhead & Leach, 1996). Detailed historical and palynological studies have also shed light on a phase of climatic disturbance and catastrophic destruction of Central African forests 2500 years (CI4) BP, events associated with a

major extension of the savanna (Maley, 2001). Furthermore, recent analysis of the organic carbon content of marine sediments⁷ from the Sierra Leone rise has provided evidence to indicate that during the past 400 000 years, the greatest intensity of vegetation fires in the West African region occurred during periods when the global climate was changing from interglacial to glacial mode (Bird & Cali, 1998).

Recent research into the pre-colonial evidence for the use of fire in West Africa has progressively improved our understanding of those vegetation cover changes in the region which have been due to nature and/or to culture. The Bird and Cali study suggests that humans in sub-Saharan Africa have actively shaped fire regimes at least during the past 10 000 years.⁸

15.2.2 Colonial Responses to Bush Fires

Complete protection is usually both impracticable and undesirable. (Moor, 1935).

Perceptions of, and attitudes to bushfires (and to the African environment in general) changed during the colonial era, and new institutional responses emerged (Tilley, 2003). As described later in this section, there were significant differences between the early and late colonial periods, and notable regional differences in the nature of resistance to early colonial conservationism.⁹ Attempts to introduce repressive bushfire control measures were integral to forest reservation policies, and were challenged throughout the colonial period particularly in terms of local struggles over land and access to woodland resources, and sometimes involved incendiarism. Repeated prominence was given to the perceived threats posed

by bushfires even though agricultural and forestry officers frequently questioned the wisdom of burning bans, and recognised the multitude of traditional economic and cultural uses of fire.¹⁰

15.2.2.1 The Early Colonial Period (1892–1939)¹¹

Although early legislation such as the 1908 Gold Coast Fires and Occurrence Inquiry Ordinance established the state's right to investigate fire-related incidents and fire damage to property,¹² it was the destructive influence of fire on vegetation (particularly forests) which preoccupied colonial administrations in the early colonial period. Fears of deforestation due to the “three evils” – “an improvident system of farming, firing and overgrazing and hacking by the shepherds” – which needed to be “judiciously regulated” (Stebbing, 1937) consistently underpinned arguments for state intervention and the regulation of forestry throughout West Africa. The destructive influence of bush fires on forest resources was a persistent theme in early colonial debates. Alfred Moloney's *Sketch of the Forestry of West Africa* drew attention to “wanton periodical burnings” and the “wanton mischief of those who take more delight in a good blaze ... and in their own ignorance, than in interest in the country” (Moloney, 1887). During an address to the Liverpool Chamber of Commerce on 19 September 1904, “Timber” Thompson outlined his vision for Forestry Departments in West Africa, and spoke of “denudation, the perils of the encroaching desert and desert fires” (Casely Hayford, 1917).¹³ These sentiments were subsequently echoed by many foresters and botanists such as Chevalier,

Aubréville, Begué and Chipp who were all instrumental in establishing forestry departments in the region during the period 1900–1935.

The early colonial period was devoted to laying the institutional and legislative foundations for state-sanctioned forestry regulation first introduced to the colonies on the West African littoral, and later to the colonies and protectorates in the hinterland (Wardell, 2002). Initially, concerns focused on the need to control exploitation of West African mahoganies, and no specific reference to bushfires is made in the earliest land and forest bills in, for example, the Gold Coast Colony.¹⁴ Forest policies and attendant legislation were subsequently based on three key principles, viz., state ownership and control of the (assumed) “vacant” forested lands; exclusion or restriction of access to forest reserves by local communities; and the use of sanctions.¹⁵ The appropriation of lands to establish forest reserves in West Africa only gained momentum after the promulgation of the Gold Coast Forests Ordinance in 1927, and the adoption, in francophone West Africa, of a pan-territorial Forestry Code in 1935. These later instruments invariably included explicit provisions with regard to the control and management of bush-fires. However, some experienced officials of the forestry administration had already suggested, by this stage, that complete fire protection was both impracticable and undesirable (Moor, 1935; Vigne, 1935).¹⁶

15.2.2.2 The Late Colonial Period (1940–1960)

The late colonial period was devoted to the consolidation of forestry departments, and to the

expansion of national networks of forest reserves. As departments were strengthened, and as the area of reserves expanded, the exclusion of fire perceived as a natural hazard became synonymous with the exclusion of people, and hence, the control of customary fire use and resource management. Forestry departments frequently usurped local rights to woodland resources as laws restricted or suspended customary communal use rights regarded as being inconsistent with rational forest management (Ribot, 1995; 1999; Bassett & Zuéli, 2000; Becker, 2001). Forest reserve boundaries were maintained by cutting firebreaks and/or using early burning to ring the protected areas, an annual collaborative effort involving forestry department technicians and local resource users hired as labourers. Fears that bushfires were also causing increased soil erosion, and hence, threatening agricultural production – perceptions fuelled by the Dustbowl experience in the United States (Stebbing, 1938; Stewart, 1944; Andersen & Grove, 1987) – added another layer to the dominant deforestation-desiccation discourse of the colonial era (Fairhead & Leach, 2000).

A number of bushfire experiments were also established in the late colonial period with the intention of investigating, in a more scientific manner, the effects of different types of fire on vegetation. The preliminary results confirmed that early fires were generally more beneficial as they did not affect processes of natural regeneration, some herbaceous vegetation remained in the landscape, and they limited the more destructive effects of late fires (Charter & Keay, 1960; Ramsay & Rose-Innes, 1963; Brookman-Amissah

et al., 1980; Louppe et al., 1995a; 1995b; Schmitz et al., 1996.). To some researchers early burning represented the only practical solution which could satisfy the diverse array of user groups in the Sudano-Sahelian landscape:¹⁷

Whatever the merits or demerits of grass-burning may be, the fact remains that at the present time and in present socio-economic conditions, fire is the only effective tool available to the peasant farmer for clearing and keeping land free of encroaching woody growth, for producing uniform grass cover free of harsh unpalatable stubble at each new grazing season and for promoting a quick flush of off-season green growth for his animals. The practice will undoubtedly continue for a long time to come and the immediate problem is how to use it to the best advantage. (Ramsay & Innes, 1963).

In spite of periodic campaigns to ban burning, a significant policy shift occurred during the late colonial period. The acceptance of early burning as a necessary tool was endorsed by the results of bushfire experiments; localised efforts in anglophone states to understand, recognise and protect customary rights to use fire;¹⁸ and in some francophone states, by new decrees adopted in the mid-1950s authorising the use of preventive early burning techniques. Colonial administrators and technicians had also, perhaps, started to recognise the futility of trying to exclude fire in the Sudano-Sahelian zone. International guidelines on bushfires remained predicated, nevertheless, upon the principles of fire control and fire suppression (Show & Clarke, 1953). Furthermore,

the shift from anti-bushfire prescriptions to recognising the benefits of early burning occurred against a dynamic backdrop of conflicting opinions, tensions between technical and political officers, and disagreements amongst forest officers and other technical line departments (Jeffreys, 1945; Nash, 1944; Wardell, 2003). This divergence of opinion and (some) scientific uncertainty may have provided sufficient fuel to ignite and resurrect anti-bushfire sentiment after independence.

15.2.3 Bush Fire Management After Independence

Any person who in a Forest Reserve without the written authority of the competent forest authority – sets fire to any grass or herbage, or kindles a fire without taking due precaution to prevent its spread ... makes or lights a fire contrary to any order of the Chief Conservator of Forests ... shall be guilty of an offence and liable on summary conviction to a fine not exceeding one thousand Cedis or to imprisonment not exceeding five years or to both. (Ghana Forest Protection Decree 1974: Section 1. (1) (c) and (d), NRCD 243).

Bushfire policies in many independent West African states continue to be informed by new bushfire “discourse coalitions”,¹⁹ and are now embedded in “modern” forest development practices (Leach & Fairhead, 2000; Amanor, 2001). They remain, in general, critical of the use of fire by rural communities although some countries such as the Gambia (Buttoud, 2001) and Burkina Faso (Government of Burkina Faso, 1998) have now broadly accepted the use of fire in rural

areas. In spite of the recent processes of decentralisation and “participatory” resource management, bushfire management strategies are often marked by a paralysing dualism – an “official system”²⁰ versus several “traditional systems” resulting from the “de-responsibilisation of the local resource users themselves” (Onibon, 2000). This is manifestly clear in terms of the mutually-exclusive knowledge of state officials (who recognise formal legislative instruments), and that of local resource users (who have, contrarily, an intricate knowledge of customary bushfire practices associated with the protection of sacred groves, land clearance, traditional millet beer-brewing and group-hunting festivals).²¹ Significant improvements in technical capacities to monitor the incidence and spatial extent of bushfires have not been matched by efforts to inform policy by understanding how and why fire is applied in Sudano-Sahelian landscapes.

15.2.3.1 Early Independence (1960–1980)

The first two decades after independence were characterised by governments keen to (re-)centralise their powers and to modernise through capital intensive investments in hydro-electric power generation, irrigated agriculture and industrial forestry plantations, invariably to the neglect of small scale resource users. “Prestige projects” facilitated the state’s prerogative to control land, precedents reinforced by increasingly restrictive forest laws. These rendered illegal most of the customary uses of the forest and/or criminalised customary practices such as the use of fire to clear crop debris or to prepare

compound farms for planting.²² These measures were enforced by successive authoritarian (often military) administrations with little scope for recourse, and despite the lack of operational funds and limited personnel which plagued Forestry Departments particularly during the 1960s.²³ “Total protection” of state forest reserves was now of paramount importance (Jouvanceau, 1962; Government of Ghana, 1974). How total fire protection was achieved, however, did vary from country to country.²⁴

The decrees accepting early burning as a necessary tool, and the detailed schedules of admitted communal rights painstakingly established during the decade prior to independence were largely forgotten by centralised states (but not by local resource users) by the late 1970s; fire suppression policies were re-introduced in many countries.

15.2.3.2 Late Independence (1981–2003)

The initial resurgence of interest in controlling bushfires in the late independence period was probably triggered by the cumulative effects of the Sahelian drought years,²⁵ the bushfire “events” in West Africa in 1983–1984 (Abebrese, 1988; Ampadu-Agyei, 1988; Malingreau et al., 1990), and a paradigm shift in forest policy.²⁶ New bushfire “discourse coalitions” (Hajer, 1995) have been forged at national and local levels shaped by these “events”, influential documents (Korem, 1985; Government of Burkina Faso, 1985), new technologies, modern bushfire actors and the convergence of local interests with global environmental management concerns. These have

resulted in either endorsing fire suppression policies or giving belated recognition (again) to the pertinence of early burning techniques. Although there has been a discernible and progressive shift from fire “control” to fire “management” by francophone forestry services in West Africa, a distinctly different pattern has developed in Ghana where the “Chief, the Forester and the Fireman”²⁷ have emerged as the dominant actors in rural bushfire policy debates.

The new coalitions have been bolstered by three distinct trends which continue to influence the relationship between bushfire “science” and “policy” in West Africa. First, the rapid expansion in the use of remotely-sensed spatial data (for example, Malingreau, 1990; Grégoire, 1993; Nielsen, 2000; Eva and Lambin, 2000) has enabled state institutions to improve their understanding of fire regimes, to monitor the spatial extent of bushfires and to envisage the development of information (control) systems for the management of fires. Second, new theoretical layers of knowledge have been added to (but in practice have not displaced) the earlier foundations of ecology and imperial forestry science which assumed succession and climax vegetation types. These layers have been shaped by indigenous knowledge discourses (Richards, 1985; Baker, 2000; Haverkort et al., 2002), more recent non-equilibrium theories (Ellis & Swift, 1988; Sprugel et al., 1991; Behnke, Scoones & Kerven, 1993; Sullivan, 1996) and the growing recognition that socio-institutional and ecological systems function as strongly linked, complex and dynamic arenas (Leach & Mearns, 1996; Fairhead & Leach, 1996). The growth of studies which aim to understand

the origins, causes and uses of fire amongst resource users has reinforced this trend (Poussy, 1992; Pyne, 1993; Hough, 1993; Kirby, 1999; Salokoski & Ouédraogo, 1999; Koku, 2001; Mbow, Nielsen & Rasmussen, 2002; Laris, 2002a; 2002b). Third, the proliferation of donor-supported environmental projects and programmes after the Sahelian crisis, and the contemporary interests in decentralisation, community participation, environmentally sustainable development, and policy-orientated seminars, have provided frameworks to construct (and re-construct) “discourse coalitions”, and to develop discursive practices (Amanor, 2001; Ribot, 2002).²⁸

A preoccupation of recent governments is the improvement of service delivery and securing greater integration of technical line ministry personnel within decentralised (or deconcentrated) government structures. Nevertheless, the implementation of new forest policies (Government of Ghana, 1994; Government of Burkina Faso, 1998) espousing “community participation” in general and specifically in bushfire management has been constrained by the limited autonomy of deconcentrated regional and district forest offices which remain divorced from local government structures. Existing bushfire-related laws continue to include unenforceable sanctions and are, in some cases, contradictory and inconsistent. In practice, organisational “cultures” have tended to prevail (Grindle, 1997)²⁹ and forest management proposals are sometimes verbatim repetitions of colonial interventions³⁰ or continue to be externally generated by central government,³¹ and/or international financiers.³²

15.3 CONTEMPORARY FIRE REGIMES IN WEST AFRICA

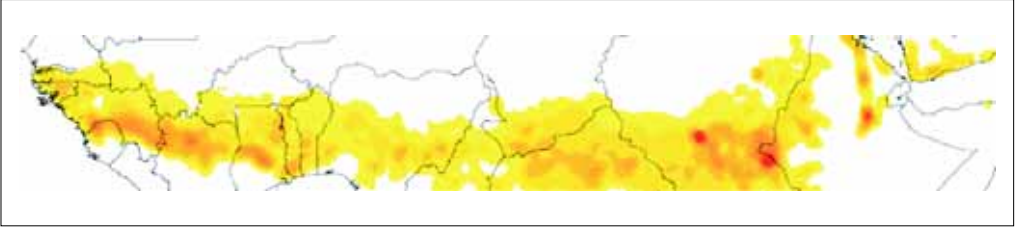
West Africa is recognised as an area of special interest with respect to fires, where large areas of the savanna are burned each year (FAO, 2001). It is estimated that as much as 80% of the total savanna area is burned on a regular basis (Menaut et al., 1991). West Africa is also characterised by a strong gradient in precipitation, from the semi-arid Sahelian zone in the north, through the Sudano-Sahelian woodlands to the Guinea forests in the south. This gradient determines to a large extent variable resource management practices, from the predominantly pastoral production systems in the north, permanent cultivation of sorghum, millets, cotton and groundnuts in the centre and the production of rice and plantation crops in the south. Thus, West Africa offers the opportunity to study the distribution of fires in time and space in a region where local perceptions, views and uses of fire, as well as the environmental and agricultural conditions influencing the use of fire, vary along this north-south axis. At a general level, the fire regimes of West Africa appear remarkably similar: as the dry season sets in, numerous fires appear in the landscape. As the dry season progresses, the fires move south burning the savanna of the Sudano-Sahelian and Sudano-Guinean belts until the fires reach the transition forest zones to the south. Although some of these fires may occur due to natural causes such as lightning, the vast majority are lit by farmers, herders or other resource user groups (Langaas, 1992; Nielsen et al., 2003). Each fire actor (or user group) is motivated under particular circumstances to achieve a particular end

(Hough, 1993; Schmitz et al., 1996). In order to protect forest reserves, the Forestry Department in Ghana may, for example, primarily be concerned with using fire as a back-burning or early burning tool when firebreaks are established. A farmer in Mali may use fire repeatedly during the dry season to clear crop debris or vegetation on fallow fields to create a mosaic of plots to be sown at the beginning of the rainy season (Laris, 2002a). Women shea nut collectors in Burkina Faso use fire to clear vegetation under shea nut trees (*Vitellaria paradoxa*), and/or to stimulate fruiting during the following season. A livestock herder in Senegal may use fire in one area to promote the regrowth of preferred grass species at the onset of the dry season whilst actively attempting to exclude, or restrict, fires in other areas.

Satellite remote sensing has provided much of the recent data for studies of the occurrence of fires (for example, Kennedy et al., 1994; Langaas, 1992; Ehrlich et al., 1997), since data can be obtained with short intervals and at a scale that allows for regional (Kaufmann et al., 1990), continental (Cahoon et al., 1992; Grégoire, 1996) or even global assessments of the extent of fires (Dwyer et al., 1998). Currently no satellite system in operation provides data at the optimal temporal interval with a spatial resolution that would allow for the identification of the smallest fires. However, the Advanced Very High Resolution Radiometer (AVHRR) sensor onboard the National Oceanic and Atmospheric Administration (NOAA) series of satellites provides data on a diurnal basis with a spatial resolution of approximately one square kilometre at a low cost.

Sampling issues of relevance to the remote sensing of fire activity include detectability, representativity and biases (Eva & Lambin, 1998). While detectability primarily relates to technical issues of the satellite sensors, representativity is an issue that has been rather poorly documented in the literature. In general, fires are detected due to their emissions of heat – for a fire to be detected it must be actively burning at the time of the satellite overpass. Research on fires in Senegal and the Gambia showed that while fire activity was at a peak in the late afternoon, coinciding with the overpass time of the NOAA satellite, fire activity remained high both before and after the passage of the satellite (Langaas, 1992). This indicates that the number of fires actually detected in the satellite image is only a fraction of the total fire activity of any given day and that the number of fires reported from studies using satellite remote sensing of active fires has to be treated with caution. Furthermore, due to technical specifications of the AVHRR sensor, active fires may be detected even if only a fraction of the one square kilometre pixel is actually affected by fire. This can limit the use of active fire products in building global models of, for example, greenhouse gas emissions since the exact area affected by fire is unknown. Finally, it should also be noted that while the physical background of active fire detection is well documented, the sampling bias due to surface cover is relatively poorly documented, and the sampling rate may be seriously influenced by the presence of high levels of crown cover while fires in grassland and savanna ecosystems remain relatively unaffected. In spite of these data limitations, it is generally

15.1



agreed that the active fire monitoring products that are being produced yield valuable information about the spatial and temporal distribution of fires throughout West Africa.³³

Fire activity across West Africa using AVHRR data for 1993 is shown in Figure 15.1.

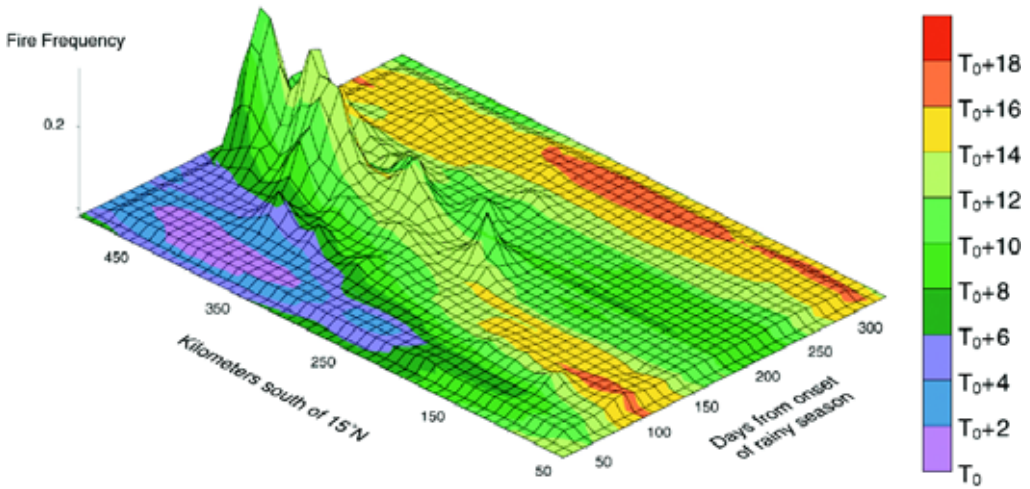
From the figure it is clear that a wide belt of fires stretches across the continent, bounded to the north by a lack of biomass and to the south by the presence of forest vegetation types. This is not to say that fires do not occur north or south of the boundaries indicated, but merely to indicate that in a typical year, the areas indicated in the figure will be most prone to fire and that the frequency of fire will be higher in the areas shown. Nevertheless, a sub-continental overview such as in the above figure will disguise many local phenomena and distribution patterns associated with fire occurrence. To illustrate this further, two cases will be discussed in more detail, Burkina Faso and Senegal.

In Burkina Faso, the temporal and spatial distribution of fires was investigated using satellite data from the AVHRR sensor (Nielsen & Rasmussen, 1997; Nielsen & Rasmussen, 2001). Active fires were detected, and the temporal and spatial distribution of fire occurrences was analysed. First, fires were analysed in relation to

various surface parameters, such as vegetation type, tree cover density, net primary production and agricultural intensity. It was found that the vast majority of fires occur in the southern parts of Burkina Faso where agricultural intensity in general is lower than in the central parts of the country, and the vegetation type is dominated by savanna woodlands. In the central areas of Burkina Faso, where much higher agricultural intensities can be found, fire frequency tended to decrease, although some areas of high fire density were found in intensively cropped areas. Fire densities were found to be significantly lower for areas with a net primary production of approximately 2000 kg/ha/y. These results indicate that fires are suppressed in the northern, low productivity areas, either due to low fuel load, by the active suppression of fires by the population, or a combination of both. Pastoral production systems in the north rely on the presence of grasses for fodder throughout the dry season, and a sudden fire early in the dry season may seriously endanger the survival of a livestock herd later in the dry season. In the central plateau where agricultural production predominates, fires occur less frequently and, generally, later in the dry season; late fires are used as a tool to clear crop residues and to open new fields. Finally, in the southern parts

Figure 15.1. Sub-continental fire density. Fire occurrences, based on an analysis of AVHRR data, were calculated and colours represent the relative density of observed (active) fires. White areas indicate no fires, or relatively low fire activity while red colours mark very high density areas. It should be noted that the fire density is bounded to the north by a lack of biomass production, while to the south it is limited by the transition from savanna and savanna woodland surface cover types to forest surface cover vegetation types.

15.2



of the country where livestock densities can also be high, herders may benefit from early fires which promote the regrowth of grass species on the basis of residual soil moisture.

This analysis was followed by a more detailed examination of the timing and location of fires in relation to the onset of the dry season. The use of early dry season fires is widespread in West Africa. In order to investigate if observed fires in Burkina Faso are predominantly early dry season fires, an estimate of the onset of the dry season was necessary. As we have discussed, however, the onset of the dry season will vary according to latitude due to the north-south precipitation gradient. Farmers in the northern parts of the country will typically observe the onset of the dry season as early as September while farmers along the border with Ghana will experience similar phenomena in November.

The land surface temperature (also obtained from satellite remote sensing) was used as a proxy

for the onset of the dry season. As soil moisture content decreases, more of the incoming solar radiation will be transformed into heat, rather than used for the (latent heat of) evaporation of water (Nielsen & Rasmussen, 2001). Thus, the onset of the dry season can be estimated as the time of the year when a rapid increase in surface temperature can be observed. The results of this analysis are shown in Figure 15.2. The temporal and spatial distribution of fires are summed in one graph, where the north-south location (measured in kilometres south of 15° N, corresponding to the north of Burkina Faso) is plotted on the y-axis, and the temporal dimension is plotted along the x-axis, representing the number of days since the 1 August. On the z-axis the observed fire frequency is plotted. The shape of the curve shows clearly that some fires are observed in the far north of Burkina Faso, but that the overwhelming majority of fires are located in the southern part of the country, typically between 250–300 km

Figure 15.2. In this 3D graph, the north-south position is plotted on the y-axis while the time of year (beginning 1 August) is plotted on the x-axis. The z-axis represents the observed fire activity while the colours indicate the surface temperature. Although the surface temperature is not indicative of fire activity *per se*, rapidly changing colours are taken to indicate the onset of the dry season when soil moisture content decreases. In the graph it can be seen that the vast majority of fires coincide

south of 15° N. It can also be seen that as we move southwards, not only is fire activity increasing, but the onset of the fire season is delayed. This would tend to confirm the earlier discussion regarding the beginning of the fire season being a function of the precipitation gradient. This argument is further strengthened when the colours of Figure 15.2 are taken into consideration. The onset of the dry season may be estimated as the time of the year when surface temperature increases suddenly corresponding, in the figure, to the change from blue violet colours to green tones. This transition coincides with the start of the burning season.

In conclusion, the fire regime of Burkina Faso was found to be dominated by early dry season fires. The numerous fires are lit early in the dry season when the impact and extent of the fire can be controlled by local resource users, and where fires are utilised in production systems. For pastoralists, these are often related to the management of grazing lands; where biological productivity is low, fires are suppressed and fires may be used by herders to promote grass regrowth in areas of higher biological productivity. In the predominantly agricultural areas, fires are also used as a tool in agricultural production systems, but where the use of fire is commonly limited to individual farmer fields. An unknown proportion of the detected fires are set for a number of other reasons including the control of pests and diseases, weed control and the collection of non-timber forest products from savanna woodlands as well as agroforestry parklands (Nielsen & Rasmussen, 1997; Nielsen & Rasmussen, 2001).

The fire regime of Senegal has been monitored using satellite imagery from the NOAA AVHRR sensor since the mid-1980s, and many years of data regarding the spatial and temporal distribution of fires in the country are available for analysis. At first glance, the fire regime of Senegal in many respects resembles that of Burkina Faso, and of West Africa in general. Observations from satellite images have shown that fires start early (October) in the northern part of the country where the herbaceous layer, dominated by annual species, dries out very quickly at the end of the short (ca. 3 months) rainy season. In the southern part, fires start later (November–December) due to the longer rainy season (ca. 6 months) and the dominance of perennial grass species (Nielsen et al., 2003). Temporal variation is influenced primarily by local variability in the amount and condition of the fuel load, as well as local perceptions of the use of fire as a natural resource management tool, particularly when contrasting rangeland areas and crop production zones (Mbow, 2000; West, 1965).

Many fires are early dry season fires, and savanna vegetation types dominate the fire regime of Senegal; approximately 85% of all fires are detected in the savanna. However, the proportion of all fires detected in cropland mosaics increases during the late dry season and the rest of the year (approximately 15%, as compared to only 4% of all fires detected during the early dry season). This tends to suggest a fire regime where early dry season fires are abundant in savanna areas. However, as the dry season continues the number of fires in the savanna decreases as fires start to appear in the cropped areas of Senegal

with the change from blue/violet colours to green colours. This would appear to indicate that the majority of fires are set at the first possible date following the end of the rainy season. It is also clear that while fires do occur even in the extreme northern parts of the country, the majority of fires occur in the southern parts of Burkina Faso (Nielsen & Rasmussen, 2001).

15.3



(Nielsen et al., 2003).

A closer investigation of the temporal and spatial distribution of fires in Senegal reveals many local variations to this very general pattern. The most noticeable feature of the Senegalese fire regime is a very clear northern limit of fire density that runs east-west in east-central Senegal (this axis is also visible in Figure 15.1). Below this borderline, numerous early dry season fires are reported every year, while north of the line very few fires are observed.

This area was examined in detail and it was found that the distribution of fires was closely linked to local resource management practices (Mbow et al., 2002). North of the line, the grassland vegetation is dominated by annual species and the exploitation of these areas is predominantly for livestock production. Herders, either living

in the area or passing through it on their seasonal migrations south, take great precaution to preserve whatever grasses remain at the end of the rainy season, since these resources are all that will allow their herds to survive through the dry season. While some fires do occur in this area, they are rather scattered in time as well as space and are actively suppressed. In contrast, the same herders are also aware that fire at the beginning of the dry season south of the line (where tree density is higher and the herbaceous vegetation is dominated by perennial species) promotes regrowth of grasses, and thus, provides a valuable supply of fresh fodder for their herds of cattle, sheep and goats. Furthermore, their actions, at the same time, do not impair the supply of fodder resources later in the dry season.

In contrast to the numerous early dry season

Figure 15.3. The fire regimes of Senegal (Nielsen et al., 2003).

fires of south-eastern parts of Senegal, in the Casamance region fires occur at a relatively high frequency throughout the dry season although not to the same extent as in the Tambacounda region further east. Fires in the Casamance region occur mostly within croplands which suggest that these fires are related to agricultural practices, rather than livestock production. A similar pattern characterises the central peanut basin in Senegal, even though fires occur less frequently than in the Casamance. Here, fires may be utilised as protective fires when areas around crop fields, homesteads or villages are burned to prevent later more destructive fires.

Other distinct localised fire phenomena can be identified in Senegal. For example, along the Senegal River in the north of the country, irrigated production of rice is dominant and fires occur almost exclusively at the beginning of the rainy season. This is a clear indication that fire is employed as a means of preparing fields or to clear crop debris from a previous season. Similarly, in the sugar-cane producing area of Richard Toll, fires occur almost exclusively at the time of harvest.

The examples from Burkina Faso and Senegal show that the extent, location and timing of fires may be explained by reference to a range of interacting biophysical factors, ecosystem characteristics and natural resource management practices. Irrespective of legislation and its enforcement, fires continue to be employed as tools in multiple land and resource management activities, including livestock production, arable crop production, forestry and hunting. This is clearly reflected in the observed fire regimes of the region.

15.4 FIRE MANAGEMENT IN WEST AFRICA

Although there are many localised differences in the nature of historical and contemporary fire regimes, the key aspects of current fire management are broadly similar throughout the Sudano-Sahelian zone of West Africa. The application of fire in the region is primarily influenced by the biophysical characteristics of specific localities, as well as the historically-embedded patterns of land and natural resource management of local resource users and their (often) negotiated encounters with state policies, legislation and regulations. The following section uses Senegal as a case study to illustrate some of the ways in which fire is currently used as a land and resource management tool by different fire actors.

15.4.1 The Fire Issue in Senegal

As discussed in the preceding section, fire distribution in Senegal follows temporal and spatial gradients which determine different fire regimes. Fire is invariably an irreplaceable tool in vegetation management, and this assumption is (now) broadly accepted at an official level and has been incorporated in national forest legislation in some countries of West Africa including Senegal. Some bushfire policies and attendant laws now give greater recognition of the beneficial uses of fire, qualified by restrictions and, in the case of misuse, appropriate penalties. Studies have found that local actors have a profound knowledge of the differential impacts of early and late fires on the herbaceous resources, for example, in the pastoral Ferlo region of Senegal. Local livelihood strategies are broadly in accordance with the provisions of national fire legislation. Nevertheless, the

dichotomy between a state strategy which, on the one hand, accepts fire as a tool for land and resource management and, on the other, continues to herald fire as a key explanatory variable for land and resource degradation results in inevitable tensions. These two positions underpin unclear legislation and institutional responses in other countries of the region which concomitantly use, restrict and exclude fire in current land and resource management practices. In general, a broad distinction can be made between forest fire practices associated with state protected areas (e.g. national parks and forest reserves), and the management of fire on public grazing and agricultural lands.

15.4.2 Fire as a Management Tool in Protected Areas

Fire management in Senegalese Forest Reserves (*forêts classées*) has long been considered a necessary tool with few practical and operational alternatives. The genesis of accepting fire use in the management of the reserves has spanned several periods as discussed in Section 15.2. During the colonial era (before ca. 1950) repeated and unsuccessful efforts to systematically exclude fire were abandoned in favour of accepting early burning as a necessary “evil”. Thereafter, fire has come to be accepted as a useful tool but only after another campaign to criminalise the use of fire and to exclude fire from savanna landscapes were re-introduced in the immediate post-independence era (West, 1965; Wardell, forthcoming). The Forestry Department, thus, now argues that the only possibility of minimising the occurrence of late fires is to burn early in the dry

season, when the herbaceous vegetation is not very dry – the use of the so-called *feux précoces*. However, this rather general policy belies the pragmatic difficulties of ensuring that fire is used in the most appropriate way, and most critically, at the right time. This highlights another tension between broad policy prescriptions, and the need to maintain some flexibility in the application of the same. The appropriate timing in the use of fire is determined by many factors associated with estimating fuel moisture content, the prevailing weather conditions and the land morphology. To simplify matters, the Forestry Department defines the early fire period from the second half of November to the end of December. This period of time is long enough, however, to result in burning which does not necessarily meet the (policy) requirement of being considered as “early burning”. Each fire season is very much correlated with the overall duration of the rainy season, and the actual end of precipitation, which are both extremely variable. The actual condition of the vegetation, rather than prescriptive dates, should determine when early fires are to be applied. The lack of biophysical information on the fire environment is frequently the main reason why many “early burn” fires end up in practice behaving more like late fires which, ironically, the former are intended to prevent.

The normative guidance dates for conducting early burns is formally endorsed by political authorities based on a proposition from the Forestry Department. In the current decentralised context, the final decision is issued by the regional councils. In theory, the Forestry Department’s proposed dates for early burning are

based on the actual state of the vegetation in a particular area using remotely-sensed data collected and collated by themselves and other national institutions of public utility such as the Ecological Monitoring Centre (*Centre de Suivi Ecologique*). In practice, the human and fiscal resources available constrain the extent to which such estimations can take account of the large spatial and temporal variability in the condition of different types of vegetation. In addition, delays between estimating the state of the vegetative cover and the final decision to apply early burning can result in *de facto* late burns as the moisture content of the herbaceous vegetation declines.

National Parks officially should start applying early fires during a period defined by rural councils. However, budgetary constraints can result in delays which can compromise the application of “good” early burning techniques. Therefore, fires occurring in such zones are often initiated by the local communities living in the vicinity of the national parks; it is, in some respects, the local population who “run the bush”. Hence, there are some differences in how fire is used as a land and resource management tool by the state agency responsible for management of national parks and the Forestry Department.

In Senegal most of the early burning is carried out in the large national parks to the south of the dividing line and include Niokolo Koba and Delta du Saloum (Sonko, 2000). Early fires are used systematically with few, if any, degrees of precaution (such as fire control measures or using fire at different periods of the day depending on prevailing wind conditions). In these protected areas, early fires constitute a system of controlled

burning that aims to reduce fuel loads in order to minimise the impacts of late fires. This “blanket” burning approach can sometimes compromise the biological resources which the use of fire aims to protect. Both early and late burning can, in fact, contribute to reducing the biological diversity of these ecosystems.

To date, neither the Forestry nor the National Parks Department has tried to review or fine-tune their early burning practices with the aim of improving forest and ecosystem management. Whilst it is widely agreed that fires cannot be suppressed in African savanna landscapes, it is still important to develop more precise and locale-specific applications to ensure the effective use of early fires. This can be assisted by the growing body of scientific research carried out in the past decade to improve our understanding of fire risk issues using ground and satellite data for vegetation monitoring.

15.4.3 From Fire Exclusion to Restricted Use

During the colonial era as we have noted, fires were invariably considered a persistent threat, and resulted in the loss, or regression, of vegetative cover. During the early colonial period some rules were established to ban the use of fire, an initiative associated both with developments in ecological science at the time but equally the vested interests of the colonial administrations keen to identify and develop resources for exploitation: firewood for the expanding railway network in the francophone federation, timber for construction, shea butter and silk cotton fibre. This early colonial initiative was not a success and alternative bushfire management

strategies had to be found which ensured a compromise between total protection as well as the widespread customary use of fire as a land and resource management tool.

Total protection against fire could eventually expose savanna vegetation to destructive late fires due to the accumulation of biomass. Thus, the main results of the bushfire experiments discussed in Section 15.2 helped to ensure that the use of early burning techniques became a standard fire management tool in the region. However, as we have noted above, the prescription of early fires within pre-determined dates did not allow for inter- and intra-seasonal variability in biophysical conditions and hence, the condition of the vegetative cover (Mbow, 2002). Not surprisingly then – and to paraphrase a Finnish proverb – early fires could be both a good servant and a poor master (Phillips, 1965).

15.4.5 Meeting Multiple Objectives in Pluralistic Landscapes

One of the main aims of using fire as a land and resource management tool in national parks in Senegal is to improve access and visibility for tourists, primarily those willing to pay for sightings of wildlife in protected areas. This is similar to the customary use of fire for individual and group hunting activities throughout the West African region and raises a number of concerns. First, if early fire prescriptions are necessary to attract tourists, they should not at the same time compromise either habitats for the wildlife or damage the herbaceous vegetation which constitutes (directly for mammalian herbivores and indirectly for carnivorous species) their main source of food.

Second, from field observations, animal distribution in national parks is very much associated with access to permanent and/or seasonal water points. If watering holes are used as prime tourist viewing sites, the use of early fires to improve visibility is not consistent with the actual dry season distribution of wildlife around lakes, rivers and ponds. These sites are not likely to burn because of the high moisture content of the surrounding vegetation. Furthermore, little research has been undertaken to ascertain how to meet multiple objectives often associated with the use of fire, whilst mitigating the potentially negative effects associated with ecosystem functions. Several studies have suggested that there has been a progressive decline in animal species diversity since the protected areas were established. The main morphological units affected by management fires in Senegalese national parks are commonly lateritic plateau and upland areas where the diversity of wildlife and the frequency of animal visits in these zones are limited due to the scarcity of water and the paucity of food. It remains unclear in the case of Niokolo Koba National Park, where tourist numbers have been progressively falling, whether this decline is due to fire damage to wildlife habitats, decreases in animal populations associated with poaching, and/or other factors.

15.4.6 Customary Uses of Fire in Relation to National Bushfire Legislation

Multiple customary uses of fire exist throughout Senegal, independent of the formal state fire management activities of the Forestry Department and National Parks Service. Several goals

are achieved by local communities who actively use fire in their land and resource management (Mbow et al., 2002). These include the protection of property (notably household compounds or bush-farm homesteads); the clearance and preparation of field plots to be planted with annual crops; the improvement of soil fertility; the control of pests and diseases retained in crop residues; the improvement of access and visibility for hunting groups; the promotion of annual grass species by herders; the collection of a large variety of non-timber forest products including honey, shea nuts and gums; the production of charcoal in traditional earth kilns; and a complex array of rituals involving the use of fire at sacred sites to propitiate the ancestors and thereby secure the future fecundity of the land and its people. The specific goals and the particular ways in which fire is used are extremely variable, and change as a function of livelihood requirements and ecosystem diversity. The relative importance of agricultural and pastoral production systems (or a combination of the two) and the relative resource abundance or scarcity, have a pronounced bearing on fire perceptions, and hence fire regimes (Nielsen et al., 2003; Mbow et al., 2002).

In contrast to the accepted use of early burning in state-managed protected areas, the provisions of contemporary forest legislation in Senegal still include clauses that render customary uses of fire illegal and define, at least on paper, elaborate penalties to discourage such practices. However, the law is rarely enforced and Forestry Department and other public officials place greater emphasis on efforts which aim to sensitise and educate local communities on how to minimise

the use of fire, as well as damage to property, crops and woodlands (DEFCCS, 1995). This contradiction between one “official” system and another deemed “unofficial” can lead to periodic tensions between the main state and local actors, but also erects a framework of opportunity – often embedded in the heart of local politics – which enables rents to be extracted by all parties (Wardell & Lund, 2004).

Responsibility for natural resource management is increasingly being deconcentrated or devolved to local community institutions under the aegis of new local government structures in Senegal. Hence, the planning and authorisation of the use of early fires has recently become a prerogative of regional councils acting on proposals submitted by the Forestry Department and ultimately approved by the Regional Assembly. Two major difficulties are foreseen with respect to this new administrative procedure. First, regions are seldom homogeneous either in terms of their biophysical properties or their socio-political institutions and communities, both of which, as we have already discussed can have a significant effect on fire behaviour. Second, the Forestry Department has already learned that prescribing pre-determined dates to apply early fires does not necessarily ensure the most appropriate use of the tool. Decentralisation may simply shift decision-making to another level of government and it will not necessarily improve the capacities of key actors interpreting the regulations on when to apply early fires as a function of the climatic, edaphic and vegetative conditions of each specific site.

15.4.7 Moving Towards Community-based Fire Management

Repeated attempts – spanning a century – to promulgate anti-bush fire legislation, to impose sanctions, to conduct educational and awareness campaigns, to adopt political slogans, and to establish and equip bushfire control institutions have not resulted in significant changes in customary uses of fire, fire “cultures” or the incidence of bushfires in the West African region (Wardell, forthcoming). Bushfire control (or management) strategies have shifted repeatedly in Senegal as in many other countries in the region. At independence, the forest law was inherited from the former colonial administration, and gave the sole responsibility for fire management to the Forestry Department.

The colonial legacy pertaining to bushfires changed in the early 1970s as a consequence of the Sahelian drought “crisis” and associated socio-economic difficulties. At this stage the state was inundated with projects and programmes providing access to considerable human, logistical and financial means (Mbow et al., 2002). Firefighting became the prime objective of the now well-equipped Forestry Department and a remunerative occupation for local resource users employed as firefighters. These changes did not, however, result in any significant reduction in the occurrence of fires. Communities engaged in local firefighting committees, although provided initially with limited tools and equipment, did not fulfil their commitments due to the continued high frequency of fires and the lack of meaningful rewards for their efforts. The incentives to perform as local firefighters were also questioned as

the communities increasingly realised that the forest resources being protected (by them) were being exploited by “outsiders” often in collusion with representatives of the Forestry Department (Ribot, 1995; 1998; Mbow et al., 2002).

Most recently, a new forest management paradigm has emerged in Senegal which specifically encompasses fire management by and for local communities. These new approaches to fire management envisage a progressive transfer of responsibility to local communities for all aspects associated with forest resource use and protection. Some initial experiences from the Gambia and Senegal suggest that improvements can be achieved as burning has declined in many community-managed forests and woodlands. The decentralisation process is compatible with this new approach and may provide opportunities to scale up such a model in the region.

The new orientation towards community-based fire management stems partially from the failure of former approaches which relied on repressive policies or capital-intensive control methods which collapsed as soon as project-financing ended. Invariably heavy equipment such as motorised water carriers could not be maintained. Similarly, interventions based on recruiting local resource users as manpower to execute government-led fire control programmes have not proved successful. In some regions such as the Senegal Oriental and Casamance areas, fires were started deliberately by local communities in an attempt to secure the continued benefits of externally-funded projects, either in terms of paid employment or food-for-work payments in kind.

This new orientation aims to support the

organisation of local resource users to take full responsibility for fire management issues. A prerequisite for the success of this approach will be the progressive transfer of use (and eventually custodial) rights to the local communities to ensure that all benefits accrue to those who “protect and manage the bush”. To implement this vision fully will necessitate substantial legislative reform, changes in organisational cultures and improvements in accountability mechanisms for resources exploited (Ribot, 2002; Mbow, 2002). Some successful first steps have been taken in parts of the region including the Gambia, Senegal and Burkina Faso but further efforts are needed to strengthen the local structures of representation, and recourse for local resource users.

15.5 CONCLUSIONS AND PERSPECTIVES

The issue of savanna fires has been controversial for a long time and continues to be so in contemporary West Africa. Current fire management policies in the region need to be understood in the context of changing scientific and political discourses (and dogma), with distinctive histories that can be traced to metropolitan France as well as to colonial India and Burma (Wardell, forthcoming). In some countries, new bushfire “discourse coalitions” have either endorsed colonial fire suppression policies or have given belated recognition to the pertinence of early burning techniques. In others, a certain relaxation of the political attitude towards the use of fire may be observed. Public institutions in several states have accepted a policy of using fires in protected area management, although this policy and praxis

remains contested.

Many of the ecologically modern bushfire stories resonate, in several respects, with colonial bushfire discourses. A century of promulgating laws, by-laws and regulations and in conducting public awareness campaigns has not significantly altered customary uses of fire throughout the Sudano-Sahelian region. Global narratives concerning fire have, nevertheless, changed over the last century. Colonial deforestation-desiccation discourses and the perceived detrimental effects of bushfires on vegetation and hence, hydrological cycles, have been supplanted by ecologically modern concerns which focus on the global effects of bushfires on emissions of aerosols and gases and carbon storage in vegetation and soil (Crutzen & Andreae, 1990; Lacaux et al., 1995; Saarnak et al., 2003) and/or the loss of biodiversity (Braithwaite, 1996; Secretariat of the Convention on Biological Diversity, 2001).

The West African savanna zone is one of the foci of fire activity in a global context. Analyses of remotely-sensed data show a clearly defined east-west belt of frequent fires, corresponding approximately to dry woodland and woodland/cropland mosaic landscapes with mean annual rainfall of more than 500 mm. Fires do occur outside this belt but less frequently. Within this fire belt, several different “fire regimes” may be identified, mostly defined by the frequency and temporal distribution of fires. The characteristics and distribution of these regimes may be explained with reference to ecosystem properties and natural resource management practices. The concentration of early dry season fires in the dry woodland areas, suggested by national scale studies

in Burkina Faso and Senegal, reflects the widespread use of early burning as a tool for promoting new growth of grasses and herbs in areas mainly used for livestock grazing. In addition, the controlled use of early fires to protect ligneous species against later, more destructive fires is common and contributes to the observed patterns. In areas dominated by intensive, almost continuous cultivation, such as the Mossi Plateau of central Burkina Faso, the Peanut Basin of Senegal, and north-east Ghana, fires are smaller, less frequent and occur throughout the season, although a peak is observed in the late dry season when fires are used in field preparation. A mixed fire regime may, of course, be observed in areas distinguished by a rangeland/cropland mosaic, such as the southern and eastern fringes of the Peanut Basin. The Sahelian grazing lands, which are dominated by annual grasses, may in wet years experience quite large fires but are, in general, much less fire-prone. The northern boundary of the fire belt is quite well-defined and stable from year to year, probably determined by whether annuals or perennials dominate, and thus whether pastoralists find it useful to restrict or promote early dry season fires.

The protected woodland areas display features of fire regimes similar to other dry woodland areas in West Africa. In national parks fires are used in a semi-controlled manner in the early dry season as “protective” fires and in order to promote wildlife visibility. The management of these fires by national park authorities has been questioned. In order to mitigate the loss of biodiversity or changes in species distribution towards fire resistant species, precise timing in

the use of fire is required, and this is not always achieved. In addition, poachers and traditional hunting groups use fire during their hunting activities, which can cause additional problems. In forest reserves (*forêts classées*) forest officials, pastoralists and hunters use early dry season fires to protect woody species, to promote grass regrowth and to improve visibility respectively. In practice, little effective control and management of the use of fire is exercised, making these areas foci of fire activity in the early dry season.

The future research on the extent, causes and effects of bushfires is likely to become part of an integrated Earth System Science, combining diverse interests in biodiversity, ecosystem structure and function, land use/cover change, carbon storage, gas and aerosol emissions and human dimensions, as exemplified by the current Land Use and Cover Change project and the upcoming Global Land Project. Better scientific understanding of the phenomenon may be expected from such integrated approaches, overcoming the traditional lack of communication between natural and social scientists, which is particularly debilitating in the case of bushfires where human and biophysical aspects are inextricably linked. In order to contribute to improving our understanding of savanna fires in West Africa, the future research agenda may include a number of components:

- The potential use of ecological modelling approaches for the reconstruction of natural fire regimes (e.g. Li, 2000).
- The further development of methods and tools to assess the extent, timing and effects of fires, and the development of applied forest

fire information systems (e.g. Burk et al., 1997; Sphyris 2000). There is considerable scope for improving Earth Observation methods, taking advantage of a range of new and planned satellite/sensor systems.

- More detailed studies to assess the negative and positive effects of fires, at the local, national and global scale, as a basis for assigning social and economic costs and benefits, and delineating responsibilities for the same (e.g. Quah & Johnston, 2001; Quah, 2002).

Whether the results of such research will translate into effective management recommendations, policies and institutional arrangements which differ from the current situation, is a difficult question to answer. A number of factors are likely to influence future science-policy debates on fire issues in West Africa. These include:

- A better understanding of local effects, both positive and negative, of various fire management strategies may lead to more locally adapted and acceptable policies, allowing farmers and pastoralists to use fire in a more controlled and rational manner. However, there are a number of conflicts of interests between different fire-user groups, making consensus on fire policy in the pluralistic landscapes of West Africa *a priori*, difficult to obtain.
- Concerns for biodiversity conservation are growing, both in the rich countries and less developed countries. Thus, evidence of the effects of fire on biodiversity is likely to have increasing influence in shaping national bush-fire policies. This will be particularly relevant

to fire policies and practices in protected areas such as national parks and forest reserves.

- The anticipated future importance of the Clean Development Mechanism of the Kyoto Protocol (or some future substitute) will also tend to direct attention to the effects of fire on carbon storage in vegetation, and (at some as yet undefined future date) perhaps in soils. While currently being referred to as “a disturbance” in the IPCC literature, the understanding of the causes and effects of fire must be integrated in the guidelines for CDM projects, which may in turn have implications in the way policies on fire are designed, particularly in relation to savanna woodlands.

ENDNOTES

- 1 Several types of fire occur in West Africa and are described using varying nomenclature used in discourses and literature. The terms employed include amongst others *prescribed fire*, *wildland fire*, *bushfire*, *wild fire*, *controlled fire*, *grassland fire* and *biomass burning*. Three broad categories of fire will be referred to in the course of this chapter: 1) Fire exclusion, referring to areas where few, if any, fires occur. 2) Early dry season fires, which occur at the beginning of the dry season. The term will be used without reference to the impact of a particular fire or the different reasons explaining the origins or causes of the fire. The term *feux précoce*, widely-used in francophone West Africa, is only referred to in the context of using early burning techniques as a land and resource management tool. 3) Late dry season fires, which occur towards the peak, or end of the dry season. Late dry season fires may, in some cases, include fires at the beginning of the rainy season. These broad distinctions are used here for the simple reason that customary perceptions in West Africa also tend to utilise this classification scheme and much research in the region has been devoted to investigations of the advantages and disadvantages of early and

late dry season fires, and of total protection against fire. There is, however, no clear or formal distinction between when a fire is classified as either an early or as a late dry season fire.

- 2 Professor E.P. Stebbing visited Nigeria, Ghana, Ivory Coast and Sierra Leone in 1934. Stebbing was Inspector-General of the Indian Forest Service during the period 1900–1917 and then became Emeritus Professor of Forestry at the School of Forestry, University of Edinburgh. Stebbing's proposal to establish two protective green belts across West Africa to arrest the advance of the Sahara desert was contested and never implemented (Stebbing, 1937 and 1938).
- 3 Such estimations should, nevertheless, be treated with caution given the exaggerations associated with earlier global estimates and the recurrent uncertainties in quantifying annual biomass burning at the country and continental scales.
- 4 A region which, in terms of land degradation processes, has recently been characterised as “the quintessence of a major environmental emergency” (Raynaut et al., 1997).
- 5 An exception is the oft-cited *Periplus* of Hanno, an ancient traveller who sailed through the Pillars of Hercules and down the west coast of Africa to establish a Carthaginian commercial colony. He saw mysterious and terrifying fires by night in an inhabited region – “a land full of flame and in the midst was a lofty fire, greater than the rest and seemed to touch the stars” (cited in Stewart, 1956). This was explained – first in 1790 by James Bruce in his *Travels to Discover the Source of the Nile, in the years 1768–1773* and subsequently endorsed by several modern authors – as the annual burning-over of the grazing region south of the Sahara.
- 6 The forest botanist T.F. Chipp who worked with the Forestry Department in the Gold Coast believed that sparks generated from boulders falling on rocks may have ignited natural fires (Chipp, 1927). More recently, Sindre Langaas has suggested that the explosion of baobab fruits (*Adansonia digitata*) is also a natural cause of bushfires (Langaas, 1992).
- 7 The sediment comprises remains of marine invertebrates, foraminifers, amorphous silica and wind dust containing elemental carbon produced by the burning of terrestrial biomass. If sampled at a sufficient distance from the coast – to ensure that the burn “signal” is integrated over a sufficiently large continental area and hence, not sensitive to latitudinal changes in vegetation due to climatic fluctuations – the sediment cores provide a relatively undisturbed and continuous record of wind-blown debris derived from woodland and savanna fires.
- 8 Additional evidence from Lake Bosumtwi in southern Ghana suggests that 10 000 years ago human activity was responsible for the concentration of a forest tree *Canarium schweinfurthii* in an area otherwise characterised by moist savanna vegetation (Hall et al., 1978 cited in: Clark, 1980).
- 9 Repeated attempts to enact land and forest legislation in southern Ghana (giving powers to both the Traditional Councils and/or to the colonial administration to establish forest reserves) met with sustained resistance for more than 30 years from an alliance of European merchants, their native middle-class intermediaries, customary chiefs, lawyers and intellectuals. The Gold Coast Forests Ordinance No. 13, Cap. 157 was only passed by the Legislative Council in March 1927 and amended by Ordinances No. 16 of 1928, No. 31 of 1928, No. 38 of 1929 and No. 10 of 1932. The Forests Ordinance, No. 4 of 1929 applied to the Northern Territories. *Forestry 1921–1930* (NAG ADM 56/1/280 Accra). By 1939 the Forestry Department had established a total of 214 forest reserves covering 15 000 km² of forested land in present-day southern Ghana, ostensibly to meet local needs for forest products, to create a suitable local climate for agriculture (especially cocoa production) and to safeguard water supplies. The Department was, in contrast, poorly established in the Northern Territories – only 160 km² of forest reserve had been constituted in the Protectorate by this stage (Wardell, 2002 and 2004).
- 10 Agricultural Superintendent Charles W. Lynn published a seminal study of customary agricultural practices in 1937 in which he acknowledged, for example, that “the burning of the grass in the dry season may have been done to reduce the chance of surprise attack.” (Lynn, 1937). Slave-raiding by Samora's sofas and Babbu's warriors continued until the mid-1890s in northern Ghana.
- 11 This period encompasses the period during which Treaties of Friendship and Trade were being negotiated by representatives of the French, British and German empires in the hinterlands of the Gold Coast Colony. The Protectorate of the Northern Territories of the Gold Coast Colony was only formally established in 1901.

- 12 The 1908 Fires and Inquiry Occurrence Ordinance, Cap. 169 as applied to the Northern Territories of the Gold Coast Colony, No. 3, Section 20. In one enquiry held at Jirapa on 12–13 March 1927 by Lt. Col. P.F. Whittall, Acting Commissioner of the Northern Province and Captain St. J. Eyre Smith, Ghana, the Chief of Jarapa registered the loss of his four inch 'King's Medal for African Chiefs' after his house had burned to the ground and two of his entourage had died attempting to rescue his possessions (Ghana National Archives, Accra: GNA ADM 56/1/150).
- 13 H.N. Thompson was appointed to establish the Forestry Department in Nigeria having formerly worked as an Assistant Conservator of Forests in Burma (Bryant 1997).
- 14 The Forest Bill of 9 November 1911 introduced (and rejected) by the Gold Coast Colony did not include any explicit references or provisions with regard to bushfires. Restrictions on the use of fire were implicit, however, under Section 13 (1) a) of the Bill which limited "the clearing for cultivation of any land in any Forest Reserve".
- 15 Four decrees were passed by the GGAOF on 20 July 1900 defining the forestry, land tenure, State lands and public property regimes in Senegal and its dependencies (administrative orders or *arrêtés* followed on 19 October 1900). The French Civil Code declared that "Les terres vacantes et sans Maître, dans les colonies et territoires de l'Afrique Occidentale française, appartiennent à l'Etat" (République Française 1904). A Forestry Department was first created in Ivory Coast in 1912. The Forestry and Water Service of the GGAOF and the Agriculture, Livestock and Forestry Service of Haute Volta were both established in 1923. The principles of national ownership and state control over access to and commercialisation of forest products were later formalised on 4 July 1935 when the French West African Forestry Code was adopted in Mauritania, Senegal, Guinea, Sudan, Niger, Upper Côte d'Ivoire (Upper Volta after 1947) and Dahomey. Additional administrative orders were also passed regulating the cutting of economically valuable species (such as shea nuts and African locust beans), prohibiting the consumption of certain non-timber forest products (such as the dried fruits of kapok), controlling the cutting, transport and marketing of woodfuels, and restricting the use of fire.
- 16 Herbert William Moor served as a forest officer in the Gold Coast during the period 1923 to 1943. He was born in India the son of an agent in the wool trade and honorary magistrate in Kalimpong. Moor was trained between 1911–1914 at the Imperial Research Institute and College in Dehra-Dun. After a period as a probationer and Extra Assistant Conservator of Forests in the United Provinces, India, he became Deputy Conservator of Forests in Trinidad and Tobago during the period 1918–1922. (RH MSS. Brit. Emp. s.333 (1) – s.333 (6)).
- 17 Ramsay & Rose Innes, 1963.
- 18 These were enshrined in legally-binding Proceedings and Judgements of Reserve Settlement Commissions. See, for example, the *Proceedings and Judgements of the Reserve Settlement Commission* (RSC) for the Red Volta East FR (held at Tanga on 20 November 1951) and the RSC for the Red Volta West FR (held at Zuarungu, 6–7 June 1955). See also Notes for the guidance of Reserve Settlement Commissioners and Forest Officers engaged on Reserve Settlement (NRG 8/11/21). PRAAD Tamale.
- 19 Hajer argues that a distinctive feature of "ecological modernisation" is the engagement of a broad range of new actors in environmental policy debates. Although these actors have different perceptions, interests and ways of articulating environmental "problems", they are often co-opted in "participatory" or "consultative" processes that ultimately need to simplify the "problem" as a basis for improving and (often) standardising the 'management of the environment' (Hajer, 1995).
- 20 The use of bushfire in the management of protected areas may, nevertheless, involve different state organisations such as Forestry, Wildlife and National Parks departments.
- 21 Interviews conducted in Upper East Region in northern Ghana and in Central West Region in Burkina Faso highlighted the pronounced gap which exists between the knowledge of formal legislative instruments amongst state officials (for example, the Control and Prevention of Bushfires Ordinance (PNDCL 229) in Ghana and the Code Forestier in Burkina Faso) and, in contrast, the intricate knowledge amongst resource users of customary bushfire institutions associated with sacred groves, land clearance and group-hunting festivals (Wardell, forthcoming).
- 22 Forest Protection Decree 1974 (NRCD 243); Control of Bushfires Law 1983 (PNDCL 46); PNDCL 142 Forest Protection (Amendment) Law 1986 (PNDCL 142); Control and Prevention of Bushfires Law 1990 (PNDCL 229).

- 23 Letters from the Forest Ranger, Nangodi to ACF, Navrongo dated 14 May 1964 (Ref: 80/NR/63-64) and 14 July 1964 (Ref: 98/NR/63-64). District Forest Office, Bolgatanga.
- 24 In Mali, for example, the Forestry Department's (self-proclaimed) success in achieving "total fire protection" in selected forest reserves of the Ségou Region resulted in the local populations deciding to "give up, of their own accord, the practice of early fires in their own grazing grounds..." (Jouvanceau, 1962).
- 25 The Sahelian "crisis", in this context, measured in terms of an (over-) simplified dichotomy between the socio-economic costs to farmers, herders and shea nut collectors, and the institutional (and personal benefits) accruing to Forestry Departments from the international response to the "crisis".
- 26 The early post-colonial approaches to industrial forestry and, later community-led forest plantations using exotic species were driven by simplistic supply-demand analyses of woodfuel chains. The myth of a wood fuel crisis was debunked (for example, Leach & Mearns, 1988), and Forestry Departments throughout West Africa adopted a new approach in the early 1980s by focusing on the management of natural forests and woodlands. This may have contributed to the re-emergence of colonial bushfire suppression policies as Forestry Departments were required to protect the areas "to-be-managed", many of them forest reserves.
- 27 This was inspired by and paraphrases the title of an article by Carola Lentz 'The Chief, The Mine Captain and the Politician: legitimating power in Northern Ghana' *Africa* 65 (3): 395-429.
- 28 In some countries of the region (such as Ivory Coast and Ghana), there has also been an interest in re-visiting colonial bushfire experiments (Louppe, 1995a and 1995b; Switzer, 1999).
- 29 The Forestry Department (now the Forest Services Division) in northern Ghana, for example, has maintained its identity as part of a "nationally integrated bureaucratic hierarchy" (Crook & Manor, 1998).
- 30 For example, a draft 'Mini-Strategic Plan for Red Volta West Forest Reserve' presented to the corresponding author in February 2002 by the District Forest Manager in Bolgatanga District includes verbatim, the Reserve Settlement Commission's Proceedings and Judgement of 7 June 1955 (Schedule II: Communal Admitted Rights).
- 31 The Forestry Commission introduced three proposals to develop management of forest reserves by i. promoting private sector investment in plantations, particularly of "degraded" areas; ii. co-management for non-timber forest products and watershed management and iii. contracting out for mining and other land uses (Ghana Forestry Commission, 2001).
- 32 The recently-launched Northern Savanna Biodiversity Conservation Project (NSBCP) includes proposals to manage forest reserves as "corridor biodiversity reserves" along the Red and White Volta Rivers (The World Bank, 2001).
- 33 Rather than detecting fires through their emission of heat, fires may also be detected in satellite imagery by the black, charred surface they leave behind. This approach is generally referred to as the Burned Area Assessment (BAA). Several authors have proposed various classification schemes to detect burned areas but no single, generally applicable algorithm has yet been established.

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ANNEXURE I

COMMUNITY PARTICIPATION IN INTEGRATED FOREST FIRE MANAGEMENT: SOME EXPERIENCES FROM AFRICA

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1 INTRODUCTION

The majority of wildfires in the developing countries of the tropics and subtropics, as well as in temperate-boreal countries in transition are human-caused and originate in the context of land use and land-use change. Vice versa, many land-use systems in these regions are vulnerable to wildfires. Property, health and welfare of people living in these areas are negatively affected by direct and indirect consequences of fire and smoke pollution. Active involvement of the local people has therefore been recognized as a condition for the successful implementation of fire management programmes, especially at the interfaces between or in intermix situations of wildlands, land-use systems and residential areas.

In the 1980s and 1990s a number of technical cooperation projects have been undertaken in developing countries, funded bilaterally or by international organisations (e.g. FAO and the World

Bank). Many of these projects were implemented in partnership with national institutions responsible for the prevention and control of forest fires. These projects were often designated as “Forest Fire Control” or “Forest Fire Prevention and Control” projects and had a purely technical approach: reduce fire hazard and improve fire suppression capabilities. This resulted in working predominantly with and through government agencies without engaging the local people who on the one hand apply fire in land-use systems and/or represent the major causing agents of wildfires, and on the other hand represent the sector of society most directly and adversely affected by wildfires in their livelihoods. This implies the recognition of local people as main actors and stakeholders.

The underlying concept of Integrated (Forest) Fire Management ([F]FM), also referred to as Community-Based Fire Management (CBFiM), is

to better integrate both fire and people into sustainable land use and vegetation management systems. The approach is based on the following considerations:

- *Reasons*
Fire is a spatially and temporally disperse phenomenon; difficult to control centrally, particularly in developing countries. Responsibility for control must be brought closer to those who benefit both from the use of fire, and from more control.
- *Objectives*
Rational, ecologically compatible, sustainable and safe use of fire; with few exceptions no attempt of complete cessation in the use of fire.
- *Impediments*
Difficulties arising from the definition of responsibility (or “the community”); the need for complementary policy and legislative change; definition and supply of technical and other support communities need to enable them to assume a central role in fire management.
- *Entry points*: Definition of the mechanisms, methods and policy instruments (incentives) to encourage communities to assume control and “ownership” over fire management.

Definition and “design” of IFFM/CBFiM approaches clearly depend on the complex configuration of local cultural, social, economic, political and environmental conditions. However it is necessary to establish a dialogue and negotiation process among all stakeholders concerned, from local to national.

IFFM/CBFiM concepts can be successfully realised only if all stakeholders involved in fire management agree on a distribution of responsibilities, decision-making power and resources. The process of negotiation and consensus-building requires careful consideration of different perspectives and also the pluriformity of the legal context. Existing rules are often of different and sometimes contradictory origins, e.g. laws and administration rules governed by centralistic legislation, traditional rules that may not have a legal recognition, or the weakening influence of traditional structures due to increasing cultural intermixing (migration) or other impacts of “globalisation”.

To overcome possible conflicts and deadlock situations, a combination of bottom-up and top-down approaches in defining the appropriate integrated fire management strategy, it seems to be most effective to build consensus among stakeholder groups at different levels. In the past decade the Fire Ecology Research Group (Max Planck Institute for Chemistry, c/o Freiburg University) and the Global Fire Monitoring Center (GFMC) have chosen both approaches to support the development of national Integrated Forest Fire Management programmes. Several “National Round Tables on Fire Management” have been realised in cooperation with the German Agency for Technical Cooperation (GTZ) and other international partners:

- In the aftermath of the extended fire and smoke episodes of the 1980s and in 1991 the first national long-term strategic fire management plan was initiated in Indonesia at the

International Workshop on “Long-Term Integrated Forest Fire Management in Indonesia” (Bandung, 17–18 June 1992) (Bappenas, 1992; Goldammer, 1993). This first “National Round Table on Fire Management” involved most stakeholders in fire management and in the international donor community. The Round Table resulted in a first concerted approach in building fire management capabilities in the country. One of the projects was the “Integrated Forest Fire Management” (IFFM) project designed by the GTZ in cooperation with the Fire Ecology Research Group. The community component of this largest-ever international cooperative fire management project is covered in detail by the contribution of Abberger et al. at this conference (this volume).

- In 1999 the Namibia-Finland Forestry Programme (NFFP), supported by the GFMC, convened a National Round Table on Fire Management. The National Round Table recommended a multi-stakeholder approach in fire management with particular emphasis on the involvement of regional stakeholders and local communities. The IFFM approach of NFFP, its success and limitations, as well as the results of the National Round Table are contained in this paper.
- After the large forest fires in Ethiopia in 2000 and the successful international response to assist the country in handling the fire emergency (Goldammer, 2000) the government called for a National Round Table on Fire Management in September 2000. It was recognised that Ethiopia, currently a country without

any fire management capabilities, would build its future programme on community involvement (Ministry of Agriculture, Ethiopia, 2001). The country is assisted by a FAO Technical Cooperation Programme on Fire Management.

In other countries no formal national round tables have been held prior to launching an IFFM programme. However, in these cases in-depth investigations at the community level were conducted to define the role of community participation in fire management (bottom-up approach):

- In Mongolia a sociological study was carried out to investigate the underlying causes of increased occurrence of wildfires in the steppe and forest ecosystems. Details are provided in this paper.
- In Guatemala a local Forum on IFFM has been convened in 2001 to address community involvement in the lowland rainforests of Petén. Experience gained in this local forum and in the four pilot communities constituted a key input to the national fire management strategy for Guatemala launched in 2002.

The experience gained in the above-mentioned projects and some additional observations on IFFM/CBFiM are presented in the following.

2 EXAMPLES FROM AFRICA

The organisational arrangements and procedures of national and local fire management systems vary from country to country. In the following

sections examples are given from Namibia, Zambia, Ivory Coast, Bénin and South Africa. For other national fire management systems see the country reports of this regional study. FAO (1996) and Goldammer and De Ronde (2001) give general recommendations for fire management in Africa.

2.1 Namibia

In 1996 the Forestry Department of the Ministry of Environment and Tourism selected East Caprivi Region (north-eastern Namibia) as the pilot area for the Namibia-Finland Forestry Programme (NFFP) to develop a “model” for community-based forest fire control (Jurvélius, 1999; Kamminga, 2001).

The pilot area consists of 1.2 million ha of Namibia’s best forest resources and belongs to the sub-tropical region. In terms of land tenure, most of the area is communal, but a significant part is state forest, national park and wildlife conservancy. Although the pilot area falls within the Kalahari sands zone, the relatively high rainfall (700 mm) contributes to the forests being moderately productive. Prior to the beginning of the project 70 to 80% of woodlands in the pilot region used to burn each year and almost all fires were of anthropogenic nature.

NFFP was launched on the basis of the 1996 Namibia Forestry Strategic Plan. The first phase was implemented from 1997 to 2001. NFFP had a fire component that was initially called Pilot Project for Forest Fire Control, but the name was modified to Integrated Forest Fire Management (IFFM) in 1998 in order to emphasize that fire is a legitimate land management tool, if carefully timed and used (Goldammer, 2001).

One objective of the IFFM component was assisting the Government in the elaboration of a national fire policy and regional fire management plan for East Caprivi. The main objective according to the project document, however, was “the implementation of an applicable model for integrated forest fire management, implemented by Namibians”. Major outputs were defined as:

- The Directorate of Forestry (DoF) and other agencies and stakeholders implementing applicable IFFM activities in the field with improved efficiency and effectiveness.
- National guidelines and forest fire policy developed.
- Changed attitudes and behaviour of general public towards the use of fire and burning, and its detrimental effects to the environment in Caprivi.

IFFM had the following strategies to realise these outputs:

- Support to public relations and extension activities for forest fire prevention within the government.
- At community level, training and mobilisation of community members towards improved fire control and subsidisation of cutline construction and maintenance.
- Organisation of a massive fire awareness and public education campaign through schools and local organisations in the area, involving all stakeholders. This included the production and use of written material, posters, billboards, drama, radio programmes and videos.

An interim evaluation in 1998 concluded that the results of creating a model for controlling fires in communal lands in Caprivi were encouraging (Table I).

As Table I shows, tens of thousands of local people have been involved the programme. The form of participation varied from attending drama shows, learning how to stop fires (with the programme provided tools), deciding where cutlines should be constructed within the community territory and working as paid workers on the construction or maintenance of cutlines. The overall result was that the annual area burned was reduced by 54% in the pilot area and the number of fires dropped by 70%.

During the fire season (April–November) in 1999 it was estimated that 1500 villagers were engaged in controlling wildfires in north-eastern Namibia. In addition, 1000 teachers and a total of 30 000 students received basic fire education.

In 1998 a survey was carried out to find out how local people experienced the efforts to control fires in their communities (Virtanen, 1998). The survey showed that the positive effects of better fire control on the natural resource base were widely recognised:

- Increased availability of grasses and thatch.
- Increased income from sales of grass, etc.
- Increased availability of building material.
- Plants and trees in better condition.
- More food available for people from the forest (fruits, nuts etc.).
- More food available for livestock.
- Increased income from sales of animals.
- Less diseases in livestock.
- No livestock or agri-crops killed by fire in pilot villages.
- Increased wildlife in villages controlling fire.

Another conclusion of the survey was that responsibility and authority for fire protection should be returned to the local people and removed from the government. The South African administration made the use of fire illegal and this is still the situation today. The new Draft Forest Bill, however, delegates fire management responsibilities and authority to the traditional authorities. This will hopefully lead to local communities becoming empowered and assuming ownership over fire control and management. This is crucial for the future sustainability of IFFM activities.

A recent assessment of the IFFM programme in terms of its impact on rural livelihoods in East Caprivi region showed that the negative effects (or “costs”) of wild fires and the positive effects (benefits) of improved fire control on local people’s livelihoods are not easy to quantify (Kamminga, 2001). They vary among different segments of the population and they are also site-specific, because they are defined by the overall natural resource situation (e.g. alternative resources when sections burn), local access rules (tenure), intensity of the land use system and the alternatives individual households have.

This complex relationship between the costs and benefits of IFFM activities is one of the reasons why mobilising local people to provide labour on a voluntary basis to maintain cut lines has proven to be difficult, especially when areas are utilised for collective grazing. Land tenure is

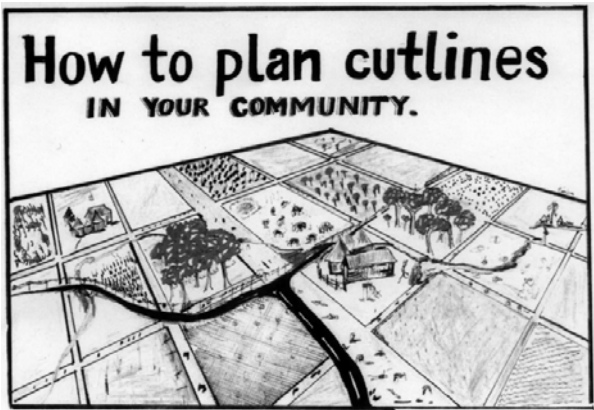
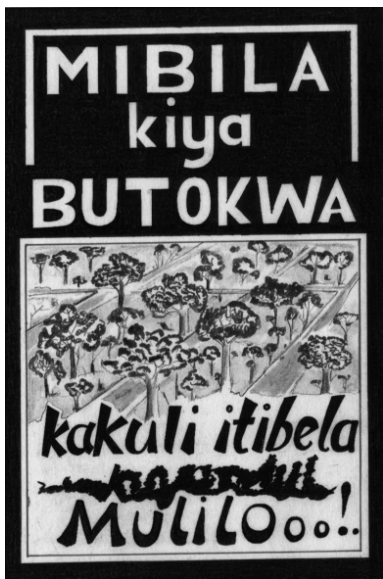
Table.1. Outputs of Integrated Forest Fire Management activities in East Caprivi between 1995 and 1998. (Note: The programme began in April 1996.)

Output Areas	Conventional Government-run Forest Fire Control 1995	Development of Integrated Forest Fire Management 1996	Development of Integrated Forest Fire Management 1997	Development of Integrated Forest Fire Management 1998
1. <i>Total area burned in East Caprivi</i>	838 000 ha	790 000 ha	558 000 ha	390 000 ha
2. <i>Area of East Caprivi burned (%)</i>	99%	91%	67%	47%
3. <i>Reduction in burned area (%)</i>	0.2%	6.0%	24%	54%
4. <i>Area under forest fire management</i>	10 000 ha	115 000 ha	396 000 ha	636 000 ha
5. <i>Area covered by fire management (%)</i>	2%	14%	48%	76%
6. <i>Area protected from fire by DoF</i>	2000 ha	–	–	–
7. <i>Area protected from fire by local communities</i>	none	50 000 ha	202 000 ha	450 000 ha
8. <i>Effectiveness of fire prevention in managed areas</i>	20%	44%	51%	71%
9. <i>Number of communities/stakeholders</i>	none	7+2 DBC+13	23+6 DBC+42	28+ DBC+24+64 *
10. <i>Fire lines or fuel breaks built (cutline)</i>	150 km	487 km	1217 km	1812 km
11. <i>People involved in fire control activities</i>	30	300	525	1000
12. <i>Number of fires observed</i>	10 000+	6000–8000	4000–6000	3000–4000
13. <i>People educated in forest fire control</i>	none	7500	13 000	33 500
14. <i>Total area burned in Namibia including prescribed burning in National Parks</i>	3–5 million ha	3–5 million ha	2.1 million ha	2.0 million ha (estim.)

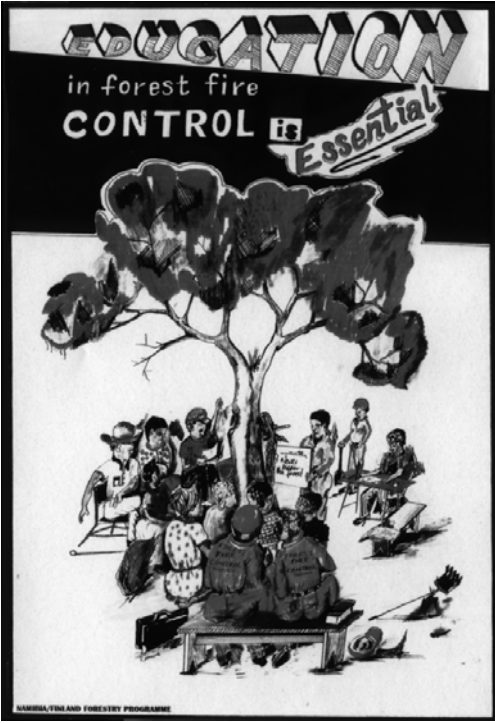
* Number of stakeholders involved in assisting the Directorate of Forestry (DoF) in forest fire prevention activities during 1998 were: 28 local communities (16 contracted), 2 Development Brigade Corporation (DBC) camps with ex-combatants of the independence movement, 24 handicraft producer villages (under the Caprivi Arts and Cultural Association (CACA) and 64 schools.

a crucial factor for community participation in fire management activities. In addition, the fire control activities (chosen techniques) must be appropriate for the specific land-use system. The woodlands of East Caprivi serve as grazing area and are utilized in an input-extensive manner. Labour-intensive techniques such as firebreaks are not economically justified from the farmers' perspective and subsidisation will always be necessary (Kamminga, 2001). The following are some of the lessons learned from the employment aspects of the IFFM model:

- There is a difference in interpretation between the IFFM programme and local people about the concept of community participation. In the IFFM model, cutline work is considered as partially voluntary (= the community's contribution) and the pay is therefore relatively low (comparable to the food-for-work system). From the perspective of cutline workers, however, the work is a job and they expect commercial wages. This confusion endangers future social and economic sustainability of the firebreaks. There must be a clear understanding and agreement between all actors concerning the character of the work.
- Providing paid work (such as IFFM involvement) in an area with high levels of unemployment, an economy that suffers from isolation due to political instability and geography, and one of the highest levels of HIV/AIDS infection in the country is a very effective way to contribute to poverty alleviation. This should be considered an objective in itself. Proper wages should be paid.
- All communities need employment and social pressure on local IFFM staff is high. Nevertheless, cutlines should only be constructed in communities where a high risk of wild fires exists. Allocation of resources should therefore take place according to a priority plan and objectively verifiable and transparent criteria. Strong supervision is necessary.
- To optimise the employment impacts, recruitment procedures should favour the poorest categories of people, in particular female heads of households. Women should be allowed to work on cutlines closest to the village, while men can do the work further away in the bush.
- Recruitment of female heads of households and married men should be encouraged, not only because they are usually more reliable and better workers, but also because there is better chance that earned money is utilised for the essential needs of the poorest household.
- Recruitment of young male school leavers for subsidised cutline work has the advantage of providing work to otherwise idle boys and also giving them some work experience, discipline, technical skills, etc. Emphasis must be put on recruiting youngsters from the resource-poorest households.
- Cutline work is and should be timed outside the agricultural season in order to avoid competition with other household labour demands.
- More frequent and timely payment of cutline work is crucial for optimising benefits for the poorest categories of people. Especially poor women cannot afford wasting their time on



Examples of fire prevention posters developed for the Namibia–Finland Integrated Fire Management Project by the local artist Kasiwa Mukenaani Saasa.



Examples of fire prevention posters developed for the Namibia–Finland Integrated Fire Management Project by the local artist Kasiwa Mukenaani Saasa.

work that does not produce an immediate or at least regular income (Kamminga, 2001).

2.1.1 National Guidelines on Forest Fire Management in Namibia

After an earlier proposal to call a National Round Table on Fire Management (Goldammer, 1998) and in accordance with the recommendations of the Round Table in 1999 (Goldammer, 2001) the IFFM assisted the government to prepare the National Guidelines on Forest Fire Management in Namibia (Jurvélius, 2001). The guidelines include a strong recommendation to include communities in forest fire protection programmes.

2.2 Zambia

Widespread burning occurs during the dry season in the rangelands, woodlands and forests of the Western Province of Zambia. Most of the fires are uncontrolled and burn large areas of both lowland grasslands and upland woodlands. Some of these fires are started deliberately, for example by livestock owners seeking to promote a green flush for their animals; by rodent hunters clearing vegetation to make it easier to find and catch their prey; by people creating firebreaks around their homesteads or seeking to improve visibility; or even by individuals playing with fire recreationally. In other cases, the fires are ignited by people clearing land for cultivation, smoking out beehives, making charcoal, cooking, or trying to keep warm while waiting at the roadside for transport. If not properly controlled, the fires spread accidentally from these points into the surrounding bush where they usually burn themselves out some distance away, often in a different vegetation type

from which they were started (Frost, 1992a). Whereas the lowlands seem to be able to sustain regular burning, many of the woodlands are beginning to show signs of damage due to too frequent and intense fires. This is exacerbated by timber extraction which is opening up the woodland canopy and allowing more light to reach the herbaceous layer, thereby promoting increased production of grass and fire-resistant shrubs that fuel the fires. These in turn kill the more fire-sensitive trees and suppress the regrowth of the more resistant species, thus preventing re-establishment of the woodland canopy, which would suppress herbaceous production, fuel loads, and fire frequency and intensity (Gambiza et al., 2000).

In addition to being technically illegal, this widespread and uncontrolled use of fire poses a number of potential problems for resource managers: shortages of fodder for livestock in the late dry season that may more than offset any benefits derived from having access to smaller amounts of higher quality forage; progressive declines in woodland cover and productivity; and the destruction of timber, fuelwood, thatching grass and other resources on which many people of the Western Province depend (Jeanes & Baars, 199; Frost, 1992b).

While recognising the benefits of burning to produce a green flush of grass for cattle, researchers and agricultural extension workers seeking to enhance cattle production and quality in the Western Province considered that too frequent and extensive burning was reducing the amount of forage for cattle in the late dry season. Consequently the Rangeland Management Team

(RMT) of the Livestock Development Programme, a joint Dutch–Zambia initiative, commissioned a review of the existing information and insights on savanna burning to provide a framework for the development and implementation of a revised policy on burning, if one was needed.

The review considered the fire regimes of the Western Province; ecological aspects of fire in southern African savanna ecosystems, including beneficial and adverse effects; fire behaviour and the factors affecting this; the use of fire in rangeland and woodland management; legal provisions then in force regarding burning; and a synthesis outlining the framework for an enhanced fire policy in the Western Province (Frost, 1992b). This review was then followed by a draft policy for fire management (Frost, 1992a) that was subsequently adopted at provincial level and implemented.

2.2.1 Fire Management Policy

A policy of planned and controlled burning of selected rangelands in the Western Province was proposed (Frost, 1992a). The policy sought to tradeoff the need for cattle to have an adequate supply of fodder of acceptable quality throughout the dry season, and the need to ensure that other users of the woodlands and rangelands of the province could continue to derive benefits from the natural resources therein. The policy also implicitly recognised that the current use of fire followed traditional practices. Consequently, it would be almost impossible to ban its use completely, as the failure of the policy at the time showed. In short, the aim of the revised policy was to maximise the benefits and minimise the

drawbacks associated with the use of fire.

People generally use fire as a tool in the management of natural resources, not as an end in itself. The use of fire also cannot be confined to any one group within a community because different people light fires for different reasons. But not everybody benefits from the occurrence of a fire (e.g. burning is likely to diminish the availability of thatch grass and timber). Therefore any attempt to institute a programme of controlled burning within a community needs to be broad-based and to address the reasons why people use fire; what they seek to gain through its use; and what the consequences might be of changing the pattern of use. In short, a strategy for controlled burning had to be developed within a broader land-use and resource-management programme.

Controlled burning requires decisions on where, when and how to burn; what preparations are needed to control the fire; coordinated actions to control the spread of the fire when burning; and cooperative management of the post-fire regrowth. Burning for the production of high quality fodder should be confined to those vegetation types, mostly the lowland moist grasslands, where sustained dry season regrowth of the grasses could be expected, even under grazing. In contrast, the upland woodlands should be protected from destructive late dry season fires through a programme of planned early burning, where this would not conflict with the interests of other users of the woodlands (Frost, 1992a).

An implementation strategy was proposed, based on a number of guiding principles. The main one was that any programme of controlled burn-

ing has to be planned with, and supported by, the community concerned. Secondly, because different people burn vegetation for different reasons, the issue of burning cannot be isolated from the circumstances surrounding its use. As such, controlled burning must be integrated into both an overall land use and resource management programme.

The strategy therefore was needed that would address the following questions.

- What level of control is required to achieve the anticipated benefits and to restrict potential detrimental effects of burning?
- Who should be responsible for exercising this control?
- How can this responsibility be instituted?
- How much and what kinds of technical advice are required to support the practice of controlled burning?
- What is the most appropriate framework for promoting this strategy of controlled burning?

There are three key elements to controlled burning: (1) preparations prior to burning, to decide upon and demarcate the areas to be burnt, and to take actions (e.g. building firebreaks) to limit the fire to the area concerned; (2) control of the fire during burning, to ensure that the fire burns the area required but does not escape into surrounding areas; and (3) post-fire management of the regrowth in relation to grazing and other forms of land use, to prevent overgrazing. All three require co-ordinated action by individuals for greatest effect. The members of a community must be

party to decisions on the need for burning and its control. They must be responsible for determining which areas can be burnt, when, how and by whom, and they must also be able to delegate these responsibilities. This emphasises the need for an integrated approach to the problem of burning among land users and co-operation at all stages. The role of technical assistance in this regard is to facilitate decision-making by the community, not to dictate the decisions.

To give effect to the policy, the RMT initiated a series of district-level workshops between December 1993 and June 1994 to develop appropriate action plans. The objectives of the workshops were to promote the revised policy aimed at achieving controlled burning in the district and to work out recommendations for an action plan to implement this policy. Workshops were held in five of the six districts of the province (Sesheke, Senanga, Kaoma, Lukulu and Kalabo) but there was apparently little interest on the part of the Mongu District Council to host a workshop in their district. This reservation on the part of the Mongu District Council was respected as community-based initiatives will not succeed if a community's sensitivities are not respected. In the case of Mongu, more work would need to be done to identify and address the source of their reservations.

Although the workshops were initiated by the RMT, the meetings were held under the auspices of the local District Council and chaired by the Council Chairman, thus making them official activities of the District Councils. Participants at the workshops included district councillors, members and representatives of the Barotse Royal Establishment, farmers, local officials of

government departments, and other interested parties. The workshops served to introduce the issues to the stakeholders and to solicit their responses and ideas to form a basis for further action.

There was general agreement at the workshops that current burning practices were not beneficial because vegetation is destroyed, resulting in the loss of natural resources such as timber and building materials; the amount of fodder for livestock is reduced; and the soil becomes denuded and prone to erosion. The uncontrolled and uncoordinated nature of burning, and the lack of technical know-how on the part of people setting fire to the vegetation, were cited as reasons for these negative effects.

Suggestions on how current burning practices could best be improved included involving traditional leaders in decision-making; more education on the responsible use of fire; the introduction of financial incentives; and improved control of the fires themselves. All the workshops strongly recommended greater involvement by communities, through their traditional leaders, together with government officials such as Natural Resources and Forestry Officers, in decisions on the use and control of fire. Responsibility for controlling burning used to be vested in traditional leaders – chiefs, *indunas* and headmen – who derived their authority from the Royal Establishment. Persons who violated local laws were prosecuted in traditional courts. Current legislation makes no direct provision for this kind of community control.

Resource management entails considerable costs in terms of time, energy, money and materials, costs that may well become onerous for

impoverished rural people. In general, they will only invest in natural resource management if they expect a clear improvement in their livelihoods or if it will reverse a situation that threatens their livelihoods. Experience elsewhere in southern Africa suggest that for community-based natural resource management institutions to be both functional and robust they need to fulfil most of the following criteria (Murphree, 1991):

- Those who manage the resources must have a vested interest in the outcome. This means that the resource managers must be the landholders and primary beneficiaries.
- There must be a close and proportional link between management inputs and benefits.
- The benefits must be tangible and immediate.
- There should be local autonomy in decision making, both in regard to management and the distribution of benefits.
- The resource user group should be small enough to be cohesive and to lower transaction costs, but not so small that it becomes exclusive and wholly self-serving.
- The leadership must be accountable, transparent and broadly representative of the community it serves.
- Responsibility at different scales should be nested to give effect to the principle of subsidiarity.
- The boundaries of management units should be distinct and exclusive (although this requirement may be difficult to implement because there is often considerable overlap between adjacent communities in the areas from which they obtain common-pool resources).

- Political and administrative boundaries of these management units should coincide broadly with the biophysical ones.

2.3 Ivory Coast and Bénin

In the years after the El Niño of 1982–83 and the extended wildfire episode of 1983, forest and bush fire control became an important priority of the environmental protection policy of the government of the Ivory Coast (Anonymous, 1996). In 1986 a National Committee of Forest Protection and Bush Fire Control was formed. Personnel of the Forest Service fill the positions of the General Secretariat and the Presidency of the National Committee. These bodies coordinate the participation of 14 ministries involved in national programmes. The task of this committee is to raise the awareness of the population of the damage caused by fires, the need for fire prevention and techniques for extinguishing fires. On the administrative level, 1500 village committees, 57 local committees and 32 regional committees were created to decentralise the task of fire control during the last ten years. These committees consist of elected members, a secretary and a president. The committees work to raise consciousness of fire threats and inform the public about fire prevention. The office of the Secretary General and the regional divisions support them in an advisory role and also play an important role in monitoring the current forest fire situation at the national level.

The contracts with the committees are paid monthly (during the four months of the dry season) and remuneration is inversely proportional to the size of the area affected by fire (Oura, 1999). The basis of payment is:

- F CFA 500 000 (US\$1000) per month per committee for 0 ha burned.
- F CFA 400 000 (US\$800) per month for less than 5 ha burned.
- F CFA 200 000 (US\$500) per month for less than 10 ha burned.
- F CFA 50 000 (US\$100) per month for less than 20 ha burned.

The average cost of surveillance is about F CFA 3000 (US\$7) per ha per year for forest plantations and F CFA 1000 (US\$2) per ha per year for natural vegetation. In Bénin, local fire committees have been created in the villages for fire prevention, detection, and suppression in collaboration with forest rangers and local agricultural officers (Tandjiékpon, 2001). After disastrous fires in 1983, Ghana also established a National Anti-Bush Fire Committee in 1984.

2.4 South Africa: Ukuvuka Operation Firestop

As shocked residents of the Western Cape Province, South Africa, watched their mountains burn in January 2000, the thought in every mind was that something urgent had to be done to prevent such devastation from occurring again. Crisis can lead to dramatic action, encouraging people to cooperate in new and creative ways. The response to this disaster was speedy, dynamic and powerful. People shared a vision of fire protection and restored ecological integrity in the Peninsula. They gave willingly of their time to translate this vision into a professional business plan that would find resources and coordinate how various authorities would act (Kruger, 2001).

Thus, the energy released by the fire gave birth to the aptly named *Ukuvuka: Operation Firestop Campaign* (*Ukuvuka* is a Xhosa word meaning “to wake up”), bringing together representatives of government, private enterprise and the media in a partnership unprecedented in South Africa.

The public sector members of the *Ukuvuka: Operation Firestop Campaign* are the National Government (represented by the Working for Water programme), the Western Cape Government, SA National Parks, the South Peninsula Municipality, the City of Cape Town and the Cape Metropolitan Council, which has committed R30 million to the campaign. Other public sector organisations are contributing staff support and expertise. The campaign’s alien clearing and ecological rehabilitation goals link closely with those of the Cape Peninsula National Park, with its generous funding from the Global Environmental Facility and the Working for Water programme.

Major private sector sponsorships have come from Santam (R20m, believed to be the largest single donation ever made to a South African environmental project), the Cape Argus (R5.5m), Nedbank (R5m) and Total (R4m). In addition, local companies and the World Wide Fund for Nature (WWF) South Africa have offered the campaign free services, ranging from the production of advertising material to legal assistance.

The campaign’s activities are governed by a Board, managed by a steering committee and overseen by independent trustees of the *Ukuvuka Trust Fund*. The campaign does not carry out ecological restoration work itself but coordinates and funds projects under the control of SA National Parks or the local authority, the City of Cape Town.

- The objectives:

Ukuvuka: Operation Firestop aims to significantly reduce the risk of damage and danger from wildfires in the Cape Peninsula.

The first key target area is the land and its plants, where the aim is to:

- Control invading alien plants.
- Rehabilitate fire-damaged areas.

The second key area are communities and individuals, by helping to:

- Create employment, training and poverty relief for disadvantaged people.
- Protect the most vulnerable communities from fire.
- Promote cooperation and social cohesion between communities.

Thirdly, institutions will be assisted to:

- Implement integrated fire management plans.
- Manage the urban edge.

The *Ukuvuka* campaign has a four-year mandate (February 2000 – March 2004) to achieve its goals. Key elements of the campaign include an effective communications and education programme and an accountable administration. The lessons learned about effective biodiversity conservation linked to social delivery will be passed on, so that the campaign becomes a role model for similar projects elsewhere in the country.

2.4.1 Working With the Land and its Plants

Since January 2000, much work has already been done to clear alien plants and rehabilitate public land. After the fires, the immediate need was for emergency measures to stabilise burned slopes, as these will only be fully secure once the natural vegetation has grown back. The spectre of post-fire flooding and mudslides was much in the minds of people who had experienced this in Glencairn and Fish Hoek the previous year. To prevent further damage and danger, the City of Cape Town worked quickly to identify 34 high-risk sites, and by the end of June 2000 they had put in place numerous anti-erosion structures, including silt curtains, sandbags and stone gabions.

Helped by a below average rainfall, this operation was a resounding success. Now, the *Ukuvuka* campaign is developing community-based nurseries to build up stocks of indigenous plants to promote the regrowth of plants in these areas. The longer-term, and more substantial, problem is the presence of invading alien vegetation. To date, some 750 tree and 8000 other plant species have been imported to South Africa for use as crops, timber, firewood, barriers or ornamental purposes. Most cause no trouble, but 198 of them have been declared weeds and invader species.

Uncontrolled, these aggressive alien plants tend to reproduce rapidly. They are thirstier than our well-adapted indigenous plants and consume billions of litres of precious water each year.

Historically, the City of Cape Town had taken action against invasive aliens and made significant strides, while currently the Cape Peninsula National Park commits more than R10 million

annually to invasive alien clearing. Freeing water is a good enough justification for a war against weeds, but another is to limit the volume of plant material available to burn in the event of a fire.

As the Peninsula found to its cost, the intensity of uncontrolled wildfires increases substantially when fire-prone aliens take root among the indigenous plants. The fuel load increases and densely invaded areas become impenetrable to firefighters, increasing the risk of disaster.

Urbanisation, agriculture and forestry have already swallowed up almost one third of the 90 000 km² Cape Floral Kingdom, and what remains (mostly in mountain areas) is threatened by invading alien plants. Indeed, these plants are the single greatest threat to the floral kingdom, regarded as the world's "hottest hotspot" for biological diversity.

Since March 2000, more than 1000 ha of alien plants have already been cleared with *Ukuvuka*: *Operation Firestop* funding, and a firebreak is being created along the 200 km boundary of the Cape Peninsula National Park. One of the campaign's first priorities was a study to identify private properties at risk, and it is working with the local authority to advise these property owners about how best to fireproof their homes.

2.4.2 What This Means for Landowners

Existing regulations require landowners to get rid of invasive alien plants, and the laws are becoming much tougher. It is in everyone's best interests to deal with these plants as quickly as possible as the longer they are ignored, the more invasive they become and the more costly to remove.

The campaign's extension officers are available to identify invasive trees and plants that must go, help find suitable contractors and oversee the clearing operation.

Some stands of alien trees have special appeal because of their historical or cultural significance, or their recreational use. They will be spared, or phased out over a gradual period. Forestry, responsible for a sizeable percentage of alien infestation, will continue in the Peninsula, but plantations will be managed very responsibly. And some hard realities will not be ignored: because poor communities have such a pressing need for fuel, some carefully controlled woodlots of alien species may be grown to provide firewood.

It's important to remember that not all alien plants are under attack – only those deemed to be a problem. Some people react emotionally when established trees are felled, but the *Ukuvuka* campaign is going out of its way to explain the threat to our rich indigenous vegetation and the increased fire risk if the spread of invasive alien plants remains unchecked.

2.4.3 Working with Communities and Individuals

2.4.3.1 Employment and Training

One of the *Ukuvuka: Operation Firestop* campaign's key objectives is to create job opportunities for as many disadvantaged people as possible. Fortunately, eradicating alien invasive vegetation is very labour intensive, and cutting down trees is only the first step. The job is not complete until all the unwanted plants have been removed or burnt, and careful follow-up clearing done to prevent regrowth – usually over several years. All this

work is being done on a contract basis. Only one person from each household is employed at any one time, so as to spread the economic benefits as widely as possible. Once skilled, they can sell their services as individual entrepreneurs on the open market.

2.4.3.2 Protecting the Most Vulnerable from Fire

Part of the campaign's mission is to empower disadvantaged people to protect their families and communities. Residents of informal settlements may not be affected by a mountain blaze, but they are always at risk from fire. Their shacks are often built of highly combustible materials and are usually clustered close together. When fire strikes one of these densely populated communities, it's often impossible to contain the resulting inferno and hundreds can lose their homes.

The campaign's target area includes five disadvantaged, fire-prone communities: Imizamo Yethu, Hout Bay fishing village, Ocean View, Masiphumelele, and Red Hill. Two vulnerable satellite areas on the Cape Flats, Joe Slovo and Silver City, will also receive help.

Last year, 30% of reported fire incidents in informal settlements in the Cape Town municipal area occurred in Joe Slovo – and 60% of all dwellings destroyed were there. Working in partnership with Disaster Management and community volunteers, the campaign has handed out 4800 buckets, whistles and informative posters in Joe Slovo. Demonstrations were given of how effectively a swift response to an alarm whistle could control a fire, using buckets of sand and water.

In each of these vulnerable areas, training in firefighting techniques, interventions to provide fire hydrants and hardened tracks that perform as access and firebreaks is underway or being investigated. Youth groups have been established to act as information officers. Fire and access breaks between homes is still needed in some areas – a step that calls for sensitive negotiation as, inevitably, some homes will have to be re-located to create the necessary space.

2.4.3.3 *Promoting Cooperation Between Communities*

Affluent people usually have fire insurance and the means to either fight a blaze or flee by vehicle. So, in their areas, the campaign will encourage landowners to manage their properties responsibly, to join forces to reduce the risk of fire and flooding, and to contribute financially to projects in the public interest.

Informal settlement dwellers, on the other hand, generally have few choices, no insurance and very little control over their environment. But with assistance from the campaign, they have the potential to become better organised, more protected from fire, and better able to respond to neighbouring communities that might be in trouble. As the previous Cape Town mayor, Nomaindia Mfeketo, pointed out, the Peninsula's mountains belong to everyone and not just to those who live on the slopes.

2.4.4 Working with Institutions

2.4.4.1 *Fire Management Plans*

An integrated fire management plan is vital if the fire-fighting activities of the various authorities

are to be best coordinated and streamlined. The Veld and Forest Fires Act (1998) makes provision for Fire Protection Associations (FPAs), and the *Ukuvuka: Operation Firestop* campaign is funding the appointment of a facilitator to establish an FPA in the Peninsula. Its primary tasks will be to help maintain firebreaks and to supervise volunteer fire-fighting groups and a rapid response system. While the FPA directs the practical operations, the campaign's input will be in the form of education, firefighting training, disaster planning and the provision of equipment.

2.4.5 Living on the Edge

People who choose to live on the mountain slopes, enjoying the beauty and advantages of the adjoining natural environment, must accept a degree of vulnerability to fire. They must also accept responsibility for protecting their immediate surroundings. There is a need for firebreaks, erosion control and fireproofing of properties along the urban fringe. There are established hack groups and nature clubs, and the campaign is supporting their efforts with planning, mapping, training, equipment and plants. As public awareness grows, it is hoped that landowners, as well as clearing alien plants and replacing them with indigenous substitutes (many of which have fire-repellent properties), will join these groups. For ordinary people to buy into *Ukuvuka: Operation Firestop*, they must care; in order to care, they must know what they stand to lose.

2.4.6 Communication

To help *Ukuvuka: Operation Firestop* achieve its objectives, there must be awareness, environ-

mental education, community enthusiasm, goodwill, pressure from insurance companies and banks, and (where necessary) legal enforcement by authorities. Campaign activities are already being widely publicised in the media. School children must also be exposed to an educational programme that will increase their knowledge about invasive alien plants and their link to fire and its consequences. Already, campaign workers and partners sport eye-catching T-shirts, and publicity initiatives include banners, bumper stickers and advertisements to inform the public of the *Ukuvuka: Operation Firestop* drive.

The campaign is a huge undertaking, but fortunately it already has the enthusiastic support of various authorities, generous funding from the private sector, and a high level of cooperation and commitment from landowners. But it's also a campaign that aims to facilitate a fundamental shift in the mindset of Capetonians; a shift that will ultimately be felt throughout South Africa as the successes of this ambitious project are duplicated elsewhere in the country.

Lessons have been learned, and although *Ukuvuka: Operation Firestop* campaign was born out of devastation and despair, its legacy will be immensely rich: rehabilitated and protected natural assets, as well as safer, more empowered communities.

3 CONCLUSIONS AND OUTLOOK

In this paper a number of projects representing a broad range of social, economic and environmental conditions have been reviewed in order to introduce IFFM/CBFiM projects or approaches outside the South East Asian region. The survey

reveals that in some countries the involvement of communities in fire management is well established. In other countries recent project proposals have defined approaches that are specifically designed to meet the local conditions. Clearly, there are many forms and degrees of community involvement.

Despite the socio-cultural variety of surveyed projects, it seems that the basic principles of community participation are rather similar throughout the different regions addressed. Most important, however, is the question if theoretical concepts of participatory approaches in fire management and successfully established pilot projects or "showcases" have resulted in a sustainable improvement of livelihoods of local populations and an increase of ecosystem stability and productivity.

When participation mainly consists of providing paid labour, the sustainability of such systems is fully dependent on continuous external cash flow and therefore will be quite problematic in many economies.

IFFM/CBFiM approaches that build upon existing traditional social structures and involve traditional leadership may not be so dependent on external cash flow and therefore are likely to be more socially and economically sustainable. However, creating an enabling environment (e.g. appropriate changes in legislation) and massive awareness raising and extension support will always be required.

Despite the experience that has been gained in IFFM/CBFiM, the authors feel that there is a need for further understanding of the concept of community participation and an inter-cultural

exchange of experience and practices. The process of international cooperation in IFFM/CBFiM will hopefully help to stimulate this development.

In order to promote the IFFM/CBFiM approach the GFMC jointly with the UN International Strategy for Disaster Reduction (ISDR) prepared the UN 2000 World Disaster Reduction Campaign which addressed community participation in fire management (ISDR, 2000). The authors express the need for an international concerted programme in conjunction with IUCN/WWF Firefight and an earlier GEF proposal by the GFMC. The International Wildland Fire Summit (Sydney, Australia, 8 October 2003) recommended that CBFiM must be promoted for the efficient reduction of uncontrolled and unwanted wildland fires.

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RECENTLY PUBLISHED

Community-based fire management: Case studies from China, The Gambia, Honduras, India, the Lao People's Democratic Republic and Turkey: This publication features case studies documenting a range of local fire management scenarios, each with a diverse set of land uses and desired outcomes. The community-based fire management (CBFiM) approaches from China, the Gambia, Honduras, India, the Lao People's Democratic Republic (Lao PDR), and Turkey presented in this publication illustrate a recent shift in direction; a movement away from centralised and state-driven forest fire management towards decentralised and mainly community-based management regimes. The book volume has been published by the FAO, Regional Office for Asia and the Pacific, Bangkok, Thailand, in 2003 (ISBN 974-7946-39-4).

Web publication: http://www.fire.uni-freiburg.de/Manag/CBFiM_3.htm

Communities in Flames: An international conference on community involvement in fire management was held in Balikpapan, Indonesia, 25-28 July 2000. The proceedings (edited by Peter Moore, David Ganz, Lay Cheng Tan, Thomas Enters and Patrick B. Durst) include examples of Definition of Community-Based Fire Management (CBFiM) from Africa, Asia, Europe and North America. The volume has been published in 2002 by the FAO, Regional Office for Asia and the Pacific Bangkok, Thailand (RAP Publication 2002/25, 133 p., ISBN 974-7946-29-7).

Web publication: http://www.fire.uni-freiburg.de/Manag/CBFiM_3.htm

Community-Based Fire Management (CBFiM): Position Paper # 5, International Wildland Fire Summit, Sydney, Australia, 8 October 2003.

ANNEXURE II

WILDLAND FIRE EMISSIONS FROM AFRICA AND THEIR IMPACT ON THE GLOBAL ATMOSPHERE

Mary Scholes
Meinrat O. Andreae

1 INTRODUCTION

In this paper we synthesize and review information on pyrogenic emissions from Africa and their impact on the global atmosphere. In a way, this task would have been much easier some six years ago, before various campaigns, such as STARE, TRACE-A and SAFARI (1, 2), took place, as there was then very little published data on this subject. Data available were mostly associated with biomass burning in the moist savannas of West Africa. Data collected during the project Fire of Savannas / Dynamique et Chimie Atmosphérique en Forêt Équatoriale (FOS/DECAFE) (3-6), together with satellite-based information focused attention on Africa as a possible source of high levels of ozone, carbon monoxide and other trace gases measured over the central South Atlantic in austral spring. At that time, widespread vegetation fires were also common in both South America and southern Africa (7-11).

The shortage of information on the emission characteristics of fires in dry savannas was one of the main reasons for organising the STARE/TRACE-A/SAFARI campaigns. Although there is a long history of fire research in southern Africa, much of the emphasis of this research had been on ecological and management effects, with little thought given to the regional and global atmospheric implications of savanna fires. Even less attention had been paid to the role of soil micro-organisms and savanna vegetation in the production of trace gases. The interactions between the sources of the trace gases and their impact on tropospheric ozone have become extremely topical issues as the data bases and knowledge have grown. This paper will present data on the emissions of trace gases from biogenic sources and biomass burning and discuss some of the impacts of these on the global atmosphere. Much of the data have been collected from particular sites in

particular seasons and attempts have been made by some authors to scale-up these values to give annual regional estimates. Problems associated with this approach will be discussed.

2 ATMOSPHERIC CHEMISTRY

The concentrations of nitrogen and oxygen that make up 99% of the Earth's atmosphere have stayed nearly constant over the last several hundred million years. The remainder of the atmosphere is made up by a variety of trace gases, and it is the concentrations of these gases that are being most significantly influenced by anthropogenic effects. Carbon dioxide (CO_2) is chemically inert in the troposphere, whereas methane (CH_4), carbon monoxide (CO), oxides of nitrogen and sulphur, and ozone (O_3) are all chemically reactive. In addition to these trace gases are other chemically reactive gases that occur in even smaller amounts, including the hydroxyl (OH) and hydroperoxy (HO_2) radicals. These free radicals are considerably more reactive than other trace gas species and, even though they have very short residence times and low average concentrations, they are crucial to gas-phase chemistry and have a particularly significant effect on atmospheric composition (12).

Tropospheric ozone is both a pollutant and an effective greenhouse gas, depending on where it occurs relative to the Earth's surface. Any changes in the processes that may lead to changes in tropospheric ozone concentrations by affecting its sources or sinks are therefore of considerable interest. Most tropospheric ozone is produced in the photochemical reaction sequences of methane and non-methane hydrocarbons (NMHCs) with

OH in the presence of nitrogen oxides (NO_x). While hydrocarbon oxidation by OH results in ozone formation in the presence of high levels of NO_x , the oxidation process in a low NO_x environment leads to ozone destruction (13).

In addition to gaseous components, the atmosphere also contains suspended solid particles, or aerosols, that have an important function in the regulation of global climate (14). They are chemically significant primarily because many gas phase molecules are removed from the atmosphere by incorporation into aerosols or by reactions occurring on particle surfaces (15).

3 EMISSIONS FROM WILDLAND FIRES

3.1 Quantity of Biomass Burned in Southern Africa

Estimates of the amounts of vegetative matter (in the following referred to as biomass) burned each year around the globe suggest that savanna fires are the single largest source of pyrogenic emissions. They are believed to be a significant source of aerosol and trace gas inputs to the global atmosphere (16-24). The primary reason for the high incidence of fires is the seasonality of the rainfall over most of the savannas areas, which allows the fuel accumulated in the growing season to become dry and prone to burning. The dry season in southern Africa lasts from May to October each year. The biomass burned annually in African savannas has been estimated at 2000 Tg dm yr^{-1} , and the area exposed to fire covers 440 million hectares (25). Estimates for Africa, south of the equator are 1200 Tg dm yr^{-1} (23). These estimates have been obtained using the

classification method, which involves using the total amount burned as the sum over the vegetation types of the product of the estimated area burned, fuel load, and fraction consumed per type.

The trend in biomass burning studies has been toward decreasing estimates of biomass burned as ecologists with local expertise have been drawn into the estimation process. For example, Menaut et al. (26) halved the estimate for west Africa by applying lower fuel loads in the extensive arid Sahelian savannas. The main reasons for these decreases are the improved estimates of the area burned when calibrated satellite data are used and the lower estimate of fuel load obtained when aridity, herbivory and decay are considered. Constraining the fuel load, by understanding the determinants of the vegetation composition and biomass, to what can be accumulated under the prevailing climate regime accounts for a further substantial part of the reduction. This approach to estimating fuel loads is termed the modelling method (27). When this method is applied to southern Africa, the estimate of the quantity of biomass burned annually and its range of uncertainty are reduced substantially relative to estimates based on extrapolation of a few point data on fuel loads to large areas and reliance on anecdotal data for estimation of the area burned.

The amount of biomass consumed annually in Africa south of the equator by vegetation fires (excluding those used for forest clearing, agricultural waste burning, and domestic biomass fuel consumption) has been estimated to average $177 \pm 87 \text{ Tg dm yr}^{-1}$ (27). Hao and Liu (28) estimated that about 2.5 times more biomass is burned in shifting cultivation in Africa than that in

deforestation. However, it is expected that this value will be much smaller when the modelling method is applied. Estimates made by Scholes et al. (27) were for a period of drought and are lower than what would be expected under normal rainfall conditions. The estimation of burned area based on detection of active fires by AVHRR or other remote sensing technologies is still in need of refinement. Regardless of source, biomass burning in the tropical forests and savannas of Africa is an important source of many of the trace gases in the atmosphere.

3.2 Emissions of Trace Gases and Aerosols from Savanna Fires in Africa

Two-thirds of tropical savannas are located in Africa, 60% of which lie south of the equator. A modelling approach has been used to estimate the emissions of CH_4 , CO , NO_x and particulate matter with a diameter smaller than $2.5 \mu\text{m}$ from vegetation fires in the region (21). The results are summarised by country in Table 1. The emissions are strongly concentrated during July–September, the Southern Hemisphere dry winter season.

Only countries completely within the study area are individually listed in the table. Note that the coarse simulation scale makes the estimates for small countries unreliable. The data are for an average year, nominally 1989, and do not include emissions from domestic fuelwood and charcoal or the burning of agricultural wastes.

The amount of CO_2 that is exchanged with the atmosphere annually owing to vegetation fires in southern Africa is very large, somewhere in the region of 20% of net primary production,

Table 1. Pyrogenic emissions of trace gases per country in Africa south of the equator (21).

Country	CO ₂ Tg/yr	CH ₄ Tg/yr	COTg/yr	NO _x Tg/yr	N ₂ OGg/yr
Angola	63.5	0.068	2.229	0.160	68.0
Botswana	13.2	0.013	0.434	0.030	7.8
Burundi	3.4	0.006	0.174	0.012	7.7
Lesotho	0.4	0.000	0.011	0.001	0.4
Malawi	7.1	0.007	0.248	0.017	11.7
Mozambique	25.6	0.033	1.035	0.072	40.3
Namibia	4.4	0.004	0.138	0.010	0.3
Rwanda	1.0	0.004	0.090	0.006	1.2
South Africa	11.4	0.015	0.449	0.031	5.8
Swaziland	0.1	0.000	0.000	0.000	0.0
Tanzania	41.0	0.015	1.623	0.114	49.5
Zambia	53.6	0.084	2.502	0.175	73.7
Zimbabwe	7.2	0.008	0.265	0.019	6.7
Others (partly included)	92.1	0.207	5.714	0.398	171.6

thus a relatively small perturbation to the fire regime could have significant consequences for the net global carbon budget. The pyrogenic methane emissions are of the same order of magnitude as emissions resulting from enteric fermentation in large mammal herbivores in the same region. The carbon monoxide emitted represents about 1% of the global CO budget and is approximately equal to the annual industrial CO emissions from the one partly industrialized country in the region, South Africa. (29). Regional pyrogenic emissions of NO_x are a significant portion of the global NO_x budget.

Estimates of the emissions of trace gases and aerosols from savanna fires in the whole of Africa and worldwide are presented in Table 2. Emission factors were calculated from the emission ratio using a mean CO₂ emission factor of 1640 g CO₂ kg⁻¹ dry fuel. The estimates of biomass burned are based on the assessments of Hao et al. (23) and Andreae (24). As noted above, investigations carried out using remote sensing and an ecosystem data base (27, 21), have resulted in much lower estimates of biomass burned in the region. However, when pyrogenic CO emissions much below those proposed in Table 2 are used as boundary

Table 2. Best guess emission factors and emission rates for savanna fires, and estimates for emissions from African and global savanna fires, all biomass burning, and all human sources (including biomass burning) (30).

Species	Molar emission ratio [10 ⁻³]	Emission factor g species/ kg dry fuel	African savannas Tg species per year	Global savannas	Biomass burning	All human sources
Biomass burned	2000	3700	8910	–		
Carbon burned	1000	1660	4100	–		
CO ₂	1000	1640	3280	6070	13500	33700
CO	62	65	130	240	680	1600
CH ₄	4	2.4	5	9	43	275
NMHC	6	3.1	6	11	42	100
H ₂	10	0.75	1.5	2.8	16	40
NO _x ²	2.8	3.1	6	11	21	70
NO _y ²	3.5	3.9	8	14	–	–
N ₂ O	0.09	0.15	0.03	0.56	1.3	5.5
NH ₃	1.5	1	2	3.7	3.7	57
SO ₂	0.25	0.6	1.2	2.2	4.8	160
COS	0.01	0.02	0.04	0.07	0.21	0.38
CH ₃ Cl ¹	0.75	0.09	0.17	0.32	1.1	1.1?
CH ₃ Br ¹	0.007	0.002	0.004	0.007	0.019	0.11
CH ₃ I ¹	0.0026	0.001	0.002	0.004	0.008	?
<i>Aerosols</i>						
TPM		10	20	37	90	390
PM _{2.5}		5	10	19	–	240
Carbon		7	14	26	60	90
Black Carbon		0.8	1.6	3	9	20
K		0.33	0.7	1.2	1.4	–
CCN		1.1·10 ¹²	22·10 ²⁷	4·10 ²⁷	35·10 ²⁷	?

¹ emission ratios relative to CO, the other emission ratios relative to CO₂

² as NO

conditions in atmospheric chemistry/transport models, unrealistically low CO concentration are obtained for stations in the tropics (15). Future studies to resolve these issues need to be carried out.

Based on the estimates of Andreae (24) savanna fires in Africa and the world account for about 22% and 42% of the biomass burned globally. However, due to the relatively clean, flaming-dominated combustion typical of savanna fires, the emission of reduced trace gases (CO, CH₄, NMHC) is less than expected from the fraction of global biomass burning that takes place in savannas. In the case of CO, savanna fires produce only 35% of the global pyrogenic emission, and in the case of CH₄, the savanna contribution is only 21%. In contrast, species that are connected to flaming combustion are favoured in savanna fires, which therefore are responsible for some 52% of pyrogenic NO_x emissions. One consequence of this flaming-dominated emission profile of savanna fires is that the ratio NO_x/NMHC in the smoke plumes is relatively high. For this reason, higher specific ozone production can take place in savanna fire plumes than in forest fire emissions (31).

Hydrogenated species (e.g. CH₄, NMHCs, CH₃Cl and CH₃Br) as well as other important trace gases (e.g., CO) are produced predominantly in smouldering conditions characterized by insufficient O₂ supply. Methyl bromide and methyl chloride play significant roles in stratospheric O₃ destruction as sources of bromine and chlorine atoms (32). Savanna fires contribute to methyl halide emissions roughly in proportion to their fraction of biomass burned, since the lower

methylation fraction due to the small amount of smouldering is compensated for by the high halogen element concentration in the savanna biomass as compared to forest biomass (30). Table 3 summarises the available information on emission ratios for CH₃Cl and CH₃Br from fires in various environments. It shows that relatively consistent results were obtained from savanna fires in different regions of Africa and South America, giving a fair degree of confidence in the accuracy of these estimates. On the other hand, the largest uncertainties regarding pyrogenic methyl halide emissions prevail in the humid tropics, where highly divergent results have been found. Future investigations need to address emissions from deforestation fires in particular.

Emission ratios are very useful for providing estimates of the biomass burning contribution to the budgets of different trace gases regionally and globally. Ratios of CO/CO₂ of 0.062 obtained during the SAFARI-92 and TRACE-A campaigns seem typical of savanna fires worldwide. Thus the emission ratios from these campaigns were employed in Table 2 to make some rough estimates of pyrogenic source strength from savannas for various gases, including the methyl halides (37, 1, 42). Worldwide estimates presented were obtained using estimates of global pyrogenic CO₂ and CO emissions of 3660 Tg C yr⁻¹ and 290 Tg C yr⁻¹, respectively (24). Even though large uncertainties are associated with data extrapolation, the calculations of savanna and worldwide emission rates for methyl halides based on these data support significant roles for the biomass burning contributions to CH₃Cl and CH₃Br to their total global emissions. The CH₃I

Table 3. Emission ratios of methyl halide species from fires in various ecosystems.

Environment	$\text{CH}_3\text{Cl}/\text{CO}$ $\times 10^6$	$\text{CH}_3\text{Cl}/\text{CO}_2$ $\times 10^6$	$\text{CH}_3\text{Br}/\text{CO}$ $\times 10^6$	$\text{CH}_3\text{Br}/\text{CO}_2$ $\times 10^6$	$\text{CH}_3\text{Br}/\text{CH}_3\text{Cl}$ $\times 10^3$	Reference
<i>Mid/High Latitude Forest</i>						
Colorado, USA		23				(33)
Various, N. America	160	12				(34)
Siberia		61		1.30	19.0	(35)
Finland	246	32	5.4	0.66	22.2	
<i>Average</i>	<i>203</i>	<i>32</i>	<i>5.4</i>	<i>0.98</i>	<i>20.6</i>	
<i>Tropical/subtropical Forest</i>						
Eucalypt Forest, Australia		290				(36)
Drakensberg, S. Africa	940	99				(37)
Humid forest, Indonesia	200	10	3.2	0.15	15.6	
<i>Best guess</i>	<i>500</i>	<i>55</i>		<i>0.83</i>		
<i>Savanna, Grassland</i>						
West Africa	500	43				(38)
Southern Africa	950	20	8.3	0.11	8.3	(37)
Southern Africa	550	30	4.1	0.23	7.5	(39)
Brazil	980	32	8.7	0.29	8.9	(39)
<i>Average</i>	<i>750</i>	<i>31</i>	<i>7.0</i>	<i>0.21</i>	<i>8.2</i>	
<i>Agricultural Wastes</i>						
Sugar cane	1050	19				(37)
<i>Laboratory Fires</i>						
Various fuels	1600	120				(40)
Various fuels		120				(41)
Savanna grass				0.29	3.4	(35)

emissions from biomass burning are more difficult to quantify, but they are likely to be insignificant in affecting global CH_3I levels compared to the large oceanic source for this gas.

Aerosols are an important by-product of biomass combustion. Recently, there has been an upsurge of interest in the potential of smoke particles to alter the radiative and chemical balance of the tropical and even global troposphere. Although smoke aerosols contain both inorganic compounds and black carbon, they consist predominantly of organic substances (43, 3, 44-46). Depending on the relative proportions of dark (e.g. soot) and non-light-absorbing components, they have the potential to create a cooling of the atmosphere by scattering incoming solar radiation, or a warming by absorbing radiation (47, 48). Furthermore, they are good cloud condensation nuclei (CCN) due to the presence of hydrophilic organic material in the particles (49, 50). Therefore, at tropical latitudes biomass burning aerosols are likely to modify the albedo and lifetime of the cloud cover (51, 52).

The production and characterisation of aerosols was studied at two sites in Africa, the Kruger National Park, South Africa, and the Lamto Research Station, Ivory Coast (45); the data collected are presented in Table 4.

Among the several trace elements detectable in biomass burning aerosols the notable and quite constant enrichment of two metals, potassium and zinc, can serve as biomass burning indicators. Chlorine and sulphur are also found in significant concentrations but their variable abundance probably reflects variable inputs of pre-deposited dust and therefore precludes any possibility for these

elements to serve as biomass burning tracers (53, 45, 46). Large uncertainties remain in the emission factor estimates for aerosols for most types of fires. This applies even more to the production of CCN from fires, therefore the values given in Table 2 must be considered as very preliminary estimates of CCN emissions. Even so, these results indicate that fires may be the largest source of CCN in the tropics (30).

4 GENERAL DISCUSSION AND CONCLUSIONS

Savanna fires are a highly significant source of trace gases and aerosol species. Due to the seasonal and regional concentration of these fires, centred on the dry tropics during the dry season, their impact is even more conspicuous. The low incidence of rain during the fire season also enhances the atmospheric lifetime of the pyrogenic pollutants, and allows them to be dispersed over long distances.

In order to generate realistic patterns of dispersal and transformation, atmospheric chemistry and climate models require trace gas and particle flux estimates for large regions, but with finer spatial and temporal resolution than current methods deliver. Reasonably accurate emission factors have now been determined for many important species. The estimates of fuel loads and emissions given by Scholes et al. (21, 27) and those used to calculate the emissions by Andreae (30) in Table 2 show how important it is to reduce the uncertainties, associated with the amount and composition of the vegetation that will burn, if we are to make accurate predictions about impacts on the atmosphere. The modelling

Table 4. Characterisation of biomass burning aerosols sampled during the two savanna experiments at Kruger National Park (KNP) and Lamto (45).

		Back fire	Head fire	Post-head fire	Smoldering fire (tree)
Fine/total TPM (%)	KNPLamto mean	84 ± 6 74 ± 8 79	80 ± 1073 ± 12 77	71 ± 13 36 54	- -
Ct/TPM (%)	KNPLamto mean	46 ± 1 58	37 ± 12mean: 7053	43 ± 243	-
Cb/Ct (%)	KNPLamto mean	9.5 ± 1.712.5 ± 2.611	10.7 ± 211.7 ± 3.311.2	11.4 ± 2 3 87	7.0 ± 0.1 7.1 7.0
K fine/K total (%)	KNPLamto mean	94 ± 289 ± 492	88 ± 1070 ± 279	71 ± 207271	64 ± 30-64
K/Cb	KNPLamto mean	1.14 ± 0.481.6 ± 1.51.4	0.98 ± 0.331.4 ± 0.91.2	0.32± 0.170.400.36	0.011 - 0.011
Zn fine/Zn total (%)	KNPLamto mean	858183	897683	735564	-
Zn/Cb (‰)	KNPLamto mean	6.7 ± 5.43.7 ± 2.15.2	4.8 ± 2.46.2 ± 3.05.5	3.35 ± 1.84.74.0	0.005-0.005
Cl fine/Cl total (%)	KNPLamto mean	91 86 89	88 77 83	61 62 61	41 - 41
Cl/Cb	KNPLamto mean	1.10 ± 0.570.43 ± 1.50.77	0.84 ± 0.300.33 ± 0.120.59	0.17 ± 0.160.370.27	0.005-0.005
S fine/ S total (%)	KNPLamto mean	7610088	717975	70 86 78	48 - -
S/Cb	KNPLamto mean	0.22 ± 0.70.036 ± 0.025-	0.19± 0.040.044-	0.20 ± 0.140.16 -	0.01



method described by Scholes et al. (21, 27) may be one way to pursue this issue. Modelling approaches to scale-up the biogenic emissions to a sub-continental scale are currently being developed. In the scenario of carbon emission limits, taxes and credits, which are now becoming very real, it will be tempting to suppress all fires in the frequently burned vegetation types (if that were practical), in order to sequester carbon. The short-term carbon gains would be substantial but insecure. In the longer term the small but steady increase in soil elemental carbon, about 400 Gg yr⁻¹, in Africa south of the equator, would no longer occur (21).

Pyrogenic emissions are mostly concentrated in the dry season from August to October, whereas the biogenic emissions are continuous throughout the year. Fire seems to have little effect on the biogenic emissions of the globally most important greenhouse gases, CO₂, CH₄ and

N₂O, whereas precipitation/soil moisture seems to have a much higher influence. The annual amount of biogenic emissions may be greater for some gases (e.g. NMHCs) than the annual pyrogenic emissions. These data will only become available as biogenic models develop. The timing of the peak of the biogenic emissions, at the onset of the spring rains, relative to the pyrogenic emissions may be important in understanding the timing of the mid-Atlantic tropospheric ozone anomaly.

The seasonal tropospheric ozone enhancement is a result of biomass burning on both sides of the South Atlantic. Modelling of biomass burning influences at a pan-tropical scale suggests that photochemical ozone production and destruction in the tropics are enhanced by 35% and 25%, respectively, causing an increase in ozone abundance in the tropical and subtropical troposphere of at least 15%. These findings have considerable

Ground-based measurements of fire emissions during the Southern Africa Fire-Atmosphere Research Initiative (SAFARI-92) were conducted in the Kruger National Park, South Africa, in August–September 1992. (Photo: J.G. Goldammer).

implications for our understanding of the role of fire in prehistoric times and of the implications of land use change and changed fire frequencies in the future.

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GLOSSARY

The following terms have been selected from the updated FAO terminology (FAO 2003, in press.*).

aerial fuel

The standing and supported live and dead fuels not in direct contact with the ground and consisting mainly of foliage, twigs, branches, stems, bark, lianas and other vines, moss and high brush. In general they easily dry out and may carry surface fires into the canopy.

agrosilvopastoral system

Land-use system in which woody perennials are used on the same land as agricultural crops and animals, in some form of spatial arrangement or temporal sequence. In fire management agrosilvopastoral systems are planned as fuelbreaks (particularly shaded fuelbreaks) to reduce fire risk by modifying understory vegetation and soil cover (cf. fuelbreak).

backfire

A fire spreading, or set to spread, into or against the wind: (1) As used in **fire suppression**: A fire set along the inner edge of a control line to consume the fuel in the path of a forest fire and/or change the direction of force of the fire's convection column (Note: doing this on a small scale and with closer control, in order to consume patches of unburned fuel and aid control-line construction

[as in mopping-up] is distinguished as "burning out, firing out, clean burning"); (2) As used in **prescribed burning**: designation of fire movement in relation to wind.

backfiring

A form of indirect attack where extensive fire is set along the inner edge of a control line or natural barrier, usually some distance from the wildfire and taking advantage of indrafts, to consume fuels in the path of the fire, and thereby halt or retard the progress of the fire front.

biomass

(1) The amount of living matter in a given habitat, expressed either as the weight of organisms per unit area or as the volume of organisms per unit volume of habitat.

(2) Organic matter that can be converted to fuel and is therefore regarded as a potential energy source. Note: Organisms include plant biomass (phytomass) and animal biomass (zoomass).

(3) In fire science the term biomass is often used synonymously with the term "fuel" and includes both living and dead phytomass (necromass); the zoomass is usually excluded.

* For additional fire terms please refer to the revised FAO Wildland Fire Management Terminology on the GFMC website: <http://www.fire.uni-freiburg.de/literature/glossary.htm>

buffer strip / buffer zone

A fuel break on the form of a strip of land along or adjacent to roads, trails, watercourses and recreation sites, or between (separating) fuel complexes (cf. fuelbreak).

candle bark

Long streamers of bark decorticated from some gum-barked *Eucalyptus* species forming a fire-brand responsible for long-distance spotting.

combustion

Consumption of fuels by oxidation, evolving heat and generally flame (neither necessarily sensible) and/or incandescence. Combustion can be divided into four phases: pre-ignition (or preheating), flaming, smouldering, and glowing.

community-based fire management (CBFiM)*Definition*

CBFiM is a type of forest and land management in which a locally resident community (with or without the collaboration of other stakeholders) has substantial involvement in deciding the objectives and practices involved in preventing, controlling or utilising fires.

Discussion / Identification

CBFiM approaches can play a significant role in fire management, especially in those places where human-based ignitions are the primary source of wildfires that affect livelihood, health and security of people. CBFiM may involve arrangements within a fire management system for communities to respond/manage fire and a shared understanding of these arrangements within the community. In some existing examples of CBFiM, communities

have the capability and authority to have effective input into land and fire management decision-making, analyse and solve problems, self regulate and adjust activities and respond to fire and other emergencies. Consequently there are a series of enabling factors that seem to allow elements of CBFiM to develop. These are:

- The community has the capacity to make implementable decisions that reflect their objectives.
- The community derives benefits from this system of fire management.
- There are *both* an internal capability and the external conditions for communities to make meaningful input into decisions on how fire is to be managed on the landscape.

control line

Comprehensive term for all constructed or natural barriers and treated fire edges used to control a fire.

dead fuel

Fuels with no living tissue in which moisture content is governed almost entirely by atmospheric moisture (relative humidity and precipitation), dry-bulb temperature, and solar radiation.

dispatcher

A person employed to receive reports of discovery and status of fires, confirm their locations, take action promptly to provide the firefighters and equipment likely to be needed for control in first attack, send them to the proper place and provide support as needed.

draped fuels

Needles, leaves, and twigs that have fallen from tree branches and have lodged on lower branches or brush. Comprises a part of aerial fuels.

drip torch

A hand-held apparatus for igniting prescribed fires and backfires by dripping flaming fuel on the materials to be burned. The device consists of a fuel fount, burner arm, and ignition source. Fuel used is generally a mixture of 65–80% diesel and 20–35% gasoline.

early burning

Prescribed burning early in the dry season, before the leaves and undergrowth are completely dry or before the leaves are shed; carried out as a precaution against more severe fire damage later in the fire season.

escaped fire

Fire which has exceeded or is expected to exceed initial attack capabilities or planned prescription.

fine fuel

Fast-drying dead fuels, generally characterised by a comparatively high surface area-to-volume ratio, which are less than 0.5 cm in diameter and have a timelag of one hour or less. These fuels (grass, leaves, needles, etc.) ignite readily and are consumed rapidly by fire when dry (cf. flash fuel).

fire behaviour

The manner in which fuel ignites, flame develops, and fire spreads and exhibits other related

phenomena as determined by the interaction of fuels, weather, and topography. Some common terms used to describe fire behaviour include the following:

smouldering – A fire burning without flame and barely spreading.

creeping – A fire spreading slowly over the ground, generally with a low flame.

running – A fire rapidly spreading and with a well-defined head.

torching – Ignition and flare up of foliage of a single tree or a small clump of trees, usually from bottom to top (syn. candler).

spotting – A fire producing firebrands carried by the surface wind, a fire whirl, and/or convection column that fall beyond the main fire perimeter and result in spot fires. Note: Solid Mass or Ember Transport under Heat Transfer.

crowning – A fire ascending into the crowns of trees and spreading from crown to crown. Note: There are three classes of crown fire under forest fire (II).

fire belt

A strip, cleared or planted with trees, maintained as a firebreak or fuelbreak.

firebreak

Any natural or constructed discontinuity in a fuelbed utilised to segregate, stop, and control the spread of fire or to provide a control line from which to suppress a fire; characterised by complete lack of combustibles down to mineral soil (as distinguished from fuelbreak).

fire climax

A plant community at a stage of succession maintained by periodic fires.

fire control

All activities concerned with the protection of vegetation from fire.

fire cycle

The number of years required to burn over an area equal to the entire area of interest.

fire danger

A general term used to express an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and fire impact; often expressed as an index.

fire danger rating

A component of a fire management system that integrates the effects of selected fire danger factors into one or more qualitative or numerical indices of current protection needs.

fire-dependent species

Plant and animal species which require regular fire influence which triggers or facilitates regeneration mechanisms, or regulates competition. Without the influence of fire these species would become extinct.

fire ecology

The study of the relationships and interactions between fire, living organisms and the environment.

fire exclusion

Planned (systematic) protection of an ecosystem from any wildfire, including any prescribed fire, by all means of fire prevention and suppression in order to obtain management objectives (cf. fire control).

fire frequency

The average number of fires or regularly occurring fire events per unit time in a designated area.

fire hazard

- (1) A fuel complex, defined by volume, type, condition, arrangement, and location, that determines the degree both of ease of ignition and of fire suppression difficulty;
- (2) A measure of that part of the fire danger contributed by the fuels available for burning. Note: Is worked out from their relative amount, type and condition, particularly their moisture contents.

fire history

The reconstruction and interpretation of the chronological record, causes and impacts of fire occurrence in an ecosystem in relation to the changes of past environmental, cultural and socio-economic conditions. Fire history evidence is based on analysis of charcoal deposits in soils, sediments, and ice, dendrochronology (fire scar analysis), historical documents, and fire reports.

fire information system

An information system designed to support fire management decisions. Advanced fire information systems integrate different sources of information required (e.g. vegetation conditions including fire

history, topography, fire weather, fire behaviour models, real-or near-real time fire detection and monitoring data, fire management resources, infrastructures and pre-suppression information) on the base of a Geographic Information System (GIS) and allows real-time distribution or access via telecommunication.

fire interval or fire-return interval

The number of years between two successive fires documented in a designated area (i.e. the interval between two successive fire occurrences); the size of the area must be clearly specified.

fire management

All activities required for the protection of burnable forest and other vegetation values from fire and the use of fire to meet land management goals and objectives. It involves the strategic integration of such factors as a knowledge of fire regimes, probable fire effects, values-at-risk, level of forest protection required, cost of fire-related activities, and prescribed fire technology into multiple-use planning, decision making, and day-to-day activities to accomplish stated resource management objectives. Successful fire management depends on effective fire prevention, detection, and pre-suppression, having an adequate fire suppression capability, and consideration of fire ecology relationships.

fire management plan

- (1) A statement, for a specific area, of fire policy and prescribed action.
- (2) The systematic, technological, and administrative management process of determining the

organisation, facilities, resources, and procedures required to protect people, property, and forest areas from fire and to use fire to accomplish forest management and other land use objectives (cf. fire prevention plan or fire campaign, pre-suppression planning, pre-attack plan, fire suppression plan, end-of-season appraisal).

fire pre-suppression

Activities undertaken in advance of fire occurrence to help ensure more effective fire suppression; includes overall planning, recruitment and training of fire personnel, procurement and maintenance of firefighting equipment and supplies, fuel treatment, and creating, maintaining, and improving a system of fuelbreaks, roads, water sources, and control lines.

fire prevention

All measures in fire management, fuel management, forest management, forest utilisation and concerning the land users and the general public, including law enforcement, that may result in the prevention of outbreak of fires or the reduction of fire severity and spread.

fire protection

All actions taken to limit the adverse environmental, social, political, cultural and economical effects of wildland fire.

fire regime

The patterns of fire occurrence, size, and severity – and sometimes, vegetation and fire effects as well – in a given area or ecosystem. It integrates various fire characteristics. A natural fire regime

is the total pattern of fires over time that is characteristic of a natural region or ecosystem. The classification of fire regimes includes variations in ignition, fire intensity and behaviour, typical fire size, fire return intervals, and ecological effects.

fire season

(1) Period(s) of the year during which wildland fires are likely to occur and affect resources sufficiently to warrant organised fire management activities.

(2) A legally enacted time during which burning activities are regulated by state or local authority.

fire suppression

All activities concerned with controlling and extinguishing a fire following its detection. (Syn. fire control, firefighting). Methods of suppression are:

direct attack – A method whereby the fire is attacked immediately adjacent to the burning fuel.

parallel attack – A method whereby a fireguard is constructed as close to the fire as heat and flame permit, and burning out the fuel between the fire and the fireguard.

indirect attack – A method whereby the control line is strategically located to take advantage of favourable terrain and natural breaks in advance of the fire perimeter and the intervening strip is usually burned out or backfired.

hot spotting – A method to check the spread and the intensity of a fire at those points that

exhibit the most rapid spread or that otherwise pose some special threat to control of the situation. This is in contrast to systematically working all parts of the fire at the same time, or progressively, in a step-by-step manner.

cold trailing – A method of determining whether or not a fire is still burning, involving careful inspection and feeling with the hand, or by use of a hand-held infrared scanner, to detect any heat source.

mop-up – The act of extinguishing a fire after it has been brought under control.

fire weather

Weather conditions which influence fire ignition, behaviour, and suppression. Weather parameters are dry-bulb temperature, relative humidity, wind speed and direction, precipitation, atmospheric stability, winds aloft.

flammability

Relative ease of igniting and burning of a given fuel under controlled conditions, with or without a pilot flame. Flammability of a fuel is characterised quantitatively by the ignition delay of a sample of fuel exposed to a normalised radiation source.

flash fuel

Fuels, e.g. grass, ferns, leaves, draped (i.e. intercepted when falling) needles, tree moss and light slash, that ignite readily and are consumed rapidly by fire when dry; generally characterized by a comparatively high surface-to-volume ratio.

forest fire

I. Definition of forest fire

Any wildfire or prescribed fire that is burning in a forest, variously defined for legal purposes. The FAO Forest Resource Assessment 2000 aims towards global standardisation of the terminology:

forest – Land with tree crown cover of more than 10% and area of more than 0.5 ha. The trees should be able to reach a minimum height of 5 m at maturity.

other wooded land – Land either with a crown cover of 5–10% of trees able to reach a height of 5 m at maturity; or a crown cover of more than 10% of trees not able to reach a height of 5 m at maturity; or with shrub or bush cover of more than 10%.

other land – Land with less crown cover, tree height, or shrub cover as defined under “Other wooded land”. Indication is desired if recurring wildfires affect “Other land” by inhibiting regeneration to the “Forest” and “Other wooded land” categories.

II. Typology

ground fire – A fire that burns in the ground fuel layer (syn. subsurface fire, *below surface fire*).

surface fire – A fire that burns in the surface fuel layer, excluding the crowns of the trees, as either a head fire, flank fire, or backfire.

crown fire – A fire that advances through the crown fuel layer, usually in conjunction with the surface fire. Crown fires can be classified according to the degree of dependence on the surface fire phase:

intermittent crown fire – A fire in which trees

discontinuously torch, but rate of spread is controlled by the surface fire phase (syn. *passive crown fire*).

active crown fire – A fire that advances with a well-defined wall of flame extending from the ground surface to above the crown fuel layer. Probably most crown fires are of this class. Development of an active crown fire requires a substantial surface fire, and thereafter the surface and crown phases spread as a linked unit (syn. *dependent crown fire*).

independent crown fire – A fire that advances in the crown fuel layer only (syn. *running crown fire*).

forest protection

That section of forestry concerned with the management of biotic and non-biotic damage to forests, arising from the action of humans (particularly unauthorised use of fire, human-caused wildfires, grazing and browsing, felling), natural wildfires, pests, pathogens, and extreme climatic events (wind, frost, precipitation).

fragmentation

The process of transforming large continuous vegetation or landscape patterns into smaller patches by disturbance. Natural agents of fragmentation are fire, landslides, windthrow, insects, erosion. Human-induced fragmentations include land use (e.g. agriculture, grazing, forestry), construction of residential areas, roads and other infrastructures. Fragmentation involves change of fire regimes due to alteration and discontinuity of fuels.

fuel

All combustible organic material in forests and other vegetation types, including agricultural biomass such as grass, branches and wood, infrastructure in urban interface areas; which create heat during the combustion process.

fuel accumulation

Process or result of build-up of those elements of a vegetation complex which are not subject to biological decay, reduction by fire, animal grazing and browsing, or harvest by humans; used in characterising fuel dynamics between two fires and implications on fire behaviour.

fuel arrangement

The horizontal and vertical distribution of all combustible materials within a particular fuel type.

fuelbreak

Generally wide (20–300 m) strips of land on which either less flammable native vegetation is maintained and integrated into fire management planning, or vegetation has been permanently modified so that fires burning into them can be more readily controlled (as distinguished from firebreak). In some countries fuelbreaks are integrated elements of agro-silvopastoral systems in which the vegetative cover is intensively treated by crop cultivation or grazing. Some fuelbreaks contain narrow firebreaks which may be roads or narrower hand-constructed lines. During fires, these firebreaks can quickly be widened either with hand tools or by firing out. Fuelbreaks have the advantages of preventing erosion, offering a safe place for firefighters to work, low maintenance,

and a pleasing appearance (cf. control line, agro-silvopastoral system, buffer strip/zone).

fuel consumption

The amount of a specified fuel type or strata that is removed through the fire process and often expressed as a percentage of the pre-burn fuel weight (or fuel load). It includes available fuel plus fuel consumed after the fire front passes.

fuel loading

The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel (consumable fuel) or total fuel, usually expressed as oven-dry weight.

fuel management

Act or practice of controlling flammability and reducing resistance to control of wildland fuels by mechanical, chemical, biological, or manual means, or by fire, in support of land management objectives.

fuel reduction

Manipulation, including combustion, or removal of fuels to reduce the likelihood of ignition, the potential fire intensity, and/or to lessen potential damage and resistance to control.

greenbelt

A fuelbreak maintained by the cultivation of strips of less flammable plants within a zone of high fire hazard, e.g. an irrigated, landscaped, and regularly maintained fuelbreak put to some additional use (e.g. golf course, park, playground).

hazard reduction

Treatment of living and dead forest fuels to reduce the likelihood of a fire starting, and to lessen its damage potential and resistance to control. Activity gaining special importance in residential/wildland interface areas.

Incident Command System

A standardized on-scene emergency management concept specifically designed to allow its user(s) to adopt an integrated organisational structure equal to the complexity and demands of single or multiple incidents, without being hindered by jurisdictional boundaries. (Element of the Incident Command System [ICS]).

Integrated Forest Fire Management (IFFM)

Designation of fire management systems which include one or both of the following concepts of integration:

- Integration of prescribed natural or human-caused wildfires and/or planned application of fire in forestry and other land-use systems in accordance with the objectives of prescribed burning.
- Integration of the activities and the use of the capabilities of the rural populations (communities, individual land users), government agencies, NGOs, POs to meet the overall objectives of land management, vegetation (forest) protection, and smoke management including “community-based fire management” or CBFiM. The term IFFM is common for fire management approaches in less developed regions including forest and non-forest ecosystems.

Note: In case of absence of forests in the area concerned the term Integrated Fire Management (IFM) is used instead (cf. community-based fire management; prescribed burning).

ladder fuel

Fuels which provide vertical continuity between strata and allow fire to carry from surface fuels into the crowns of trees or shrubs (torching, crowning) and support continuation of crown fires (cf. crown fuel, ground fuel, and surface fuel).

late burning

Prescribed burning activities towards the end of the dry season.

low intensity fire

Fire which burns with a relatively low intensity, e.g. a prescribed surface fire as opposed to a high-intensity crown fire.

pre-attack plan

A plan detailing predetermined fire suppression strategy and tactics to be deployed following fire occurrence in a given land management unit. A pre-attack plan contains data on fuel types and topographic conditions including fuelbreaks, access routes and travel times, water supply sources, lakes suitable for skimmer aircraft, and existing heliports. It also includes information on existing and/or proposed locations for control lines (including the types and number of fire suppression resources that may be required and probable rates of fireguard construction, and possible constraints), base and line camps, helispots, and the priorities for construction and/or improvement of

pre-suppression facilities (syn. pre-attack planning, pre-attack, cf. fire management plan, fire suppression plan, pre-suppression planning).

prescribed burning

Controlled application of fire to vegetation in either their natural or modified state, under specified environmental conditions which allow the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to attain planned resource management objectives (cf. prescribed fire). Note: This term has replaced the earlier term “controlled burning”.

prescribed fire

A management-ignited wildland fire or a wildfire that burns within prescription, i.e. the fire is confined to a predetermined area and produces the fire behavior and fire characteristics required to attain planned fire treatment and/or resource management objectives. The act or procedure of setting a prescribed fire is called prescribed burning (cf. prescribed burning). A wildfire burning within prescription may result from a human-caused fire or a natural fire (cf. prescribed natural fire, integrated forest fire management, wildfire).

prescribed natural fire

Naturally ignited fires, such as those started by lightning, which are further used to burn under specific management prescriptions without initial fire suppression and which are managed to achieve resource benefits under close supervision (cf. prescribed fire, wildfire).

prescription

Written statement defining the objectives to be attained as well as the conditions of temperature, humidity, wind direction and speed, fuel moisture, and soil moisture, under which a fire will be allowed to burn. A prescription is generally expressed as acceptable ranges of the prescription elements, and the limit of the geographic area to be covered.

rate of spread

The speed at which a fire extends its horizontal dimensions, expressed in terms of distance per unit of time (m/min or km/h) (syn. fire spread, cf. rate of area growth, rate of perimeter growth).

reclamation burning

Prescribed burning for restoration of ecosystem characteristics and functioning (cf. restoration).

rehabilitation

The activities necessary to repair damage or disturbance caused by wildfire or the wildfire suppression activity (cf. restoration).

residence time

- (1) The time required for the flaming zone of a fire to pass a stationary point.
- (2) The time an emission component is in the air between emission and removal from the air or change into another chemical configuration.

residential / wildland interface

The transition zone between residential areas and wildlands or vegetated fuels (cf. urban, urban/wildland interface, wildland, wildland fire, rural urban interface).

restoration

Restoration of biophysical capacity of ecosystems to previous (desired) conditions. Restoration includes rehabilitation measures after fire, or prescribed burning where certain fire effects are desired (cf. rehabilitation, reclamation burning).

ring fire

A fire started by igniting the full perimeter of the intended burn area so that the ensuing fire fronts converge toward the centre of the burn.

risk

- (1) The probability of fire initiation due to the presence and activity of a causative agent.
- (2) A causative agent.

rural fire protection

Fire protection and firefighting problems that are outside of areas covered by municipal Fire and Rescue Services and its Fire Ordinance; these areas are usually remote from public water supplies and require all terrain vehicles to reach.

serotiny

Storage of seeds in closed seed containers in the canopy of shrubs and trees. For instance, serotinous cones of Lodgepole Pine do not open until subjected to temperatures of 45 to 50°C, causing the melting of the resin bond that seals the cone scales.

slash

Debris (fuels) resulting from natural events (wind/fire) or human activities like forest harvesting.

slash disposal

Treatment of slash to reduce fire hazard or for other purposes (cf. fuel management).

smoke haze

An aggregation (suspension) in the atmosphere of very fine, widely dispersed, solid or liquid particles generated by vegetation fires giving the air an opalescent appearance.

smoke management

The application of knowledge of fire behaviour and meteorological processes to minimise air quality degradation during prescribed fires.

spot fire

- (1) Fire ignited outside the perimeter of the main fire by a firebrand (by flying sparks or embers transported by air currents, gravity, or fire whirls).
- (2) A very small fire which jumped over the fireline, that requires little time and resources to extinguish by air currents, gravity, and/or fire whirls (cf. long-range spotting).

stand replacement fire

Fire which kills all or most living overstory trees in a forest and initiates secondary succession or regrowth.

underburning

Prescribed burning with a low intensity fire in activity-created or natural fuels under a timber canopy.

urban / wildland interface

The transition zone

- (1) between cities and wildland (cf. urban, wildland, wildland fire),
- (2) where structures and other human development meets undeveloped wildland or vegetative fuels (syn. residential/wildland interface, wildland/urban interface, rural urban interface).

values-at-risk

Natural resources, developments, or other values that may be jeopardised if a fire occurs.

wilderness

- (1) A wild, uncultivated, uninhabited region, both vegetated and non-vegetated.
- (2) Area of remarkable natural beauty and ecological diversity.
- (3) Area established to conserve its primeval character and influence for public enjoyment, under uncultivated conditions, in perpetuity.

wildfire

- (1) Any unplanned and uncontrolled wildland fire which regardless of ignition source may require suppression response, or other action according to agency policy.
- (2) Any free burning wildland fire unaffected by fire suppression measures which meets management objectives (cf. wildland, wildland fire, prescribed natural fire, prescribed fire).

wildland

Vegetated and non-vegetated land in which development is essentially non-existent, except for roads, railroads, powerlines, and similar transportation facilities; structures, if any, are widely scattered. In fire management terminology this general term includes all burnable vegetation resources including managed forests and forest plantations (cf. residential/wildland interface, wildfire).

wildland fire

Any fire occurring on wildland regardless of ignition sources, damages or benefits (cf. wildland, wildfire, residential/wildland interface).

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